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RECOGNITION OF DETAIL

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THE optical and physiological properties of the eye play a very important part in the design of optical systems, and those properties are of most importance which affect or modify the capacity to see fine detail. The object of this paper is to discuss the factors which influence the recognition of detail. It will be found that there are four important factors:

(*a*) The amount of light received from each element of the detail to be observed.

(*b*) The contrast between the neighbouring parts either in brightness or colour.

(*c*) The quality of the optical images.

(*d*) The limits imposed by the diffraction of light and the aperture of the eye, and by the coarseness of the receiving elements of the retina.

If the resolution of detail were dependent only on diffraction limits it would be possible to resolve two small objects about 25 seconds apart (assuming a pupil size of about 5 mm.); this corresponds quite closely to the limit set by the size of the retinal cones, viz. ·002 mm. on a focal length of 16 mm., but the other considerations indicated above must also be taken into account.

It has long been recognised that visual acuity falls off rapidly with diminished illumination and the present author* has pointed out that under these conditions *the quantity of light* received from each unit area recognised is of the same order as that required for the recognition of a small source of light. As the direct observation of visual acuity presents difficulties and the results are not very accurate, we will first consider the observations on the limits of visibility of sources of light.

* *The Illuminating Engineer* (May 1915), 219; Discussion, Paterson and Dudding, Visibility.

Limits of Visibility.

Investigations on the quantity of light necessary to produce the sensation of brightness have been made in two ways—by measurement of the *illumination* necessary to make an extended object visible and of the candle-power of a small source of light which is just visible, but very little attempt seems to have been made to co-ordinate the results, or to consider the significance of the actual values obtained. Aubert*, among others, has measured the minimum illumination (threshold value) for an eye fully adapted to darkness. In these observations a white extended object was just visible when the illumination was equivalent to one candle at 200 to 250 metres. Sir W. Abney's† measurements confirm and extend these results; his observations were made for each part of the spectrum and they give 16×10^{-6} metre candles for the minimum illumination for the recognition of light, when the eye could choose its own most sensitive part, and the most favourable part of the spectrum was selected. If the observations were restricted to the centre of the eye the minimum illumination was increased about six times. This will be referred to as "the extinction value." The above illumination‡ is for an object subtending an angle of 1° 30′; the illumination depends on the angle, but there is no advantage in increasing this area beyond 4°.

Paterson and Dudding§ have shown that for small sources it is the total flux which determines the visibility, and they regard $\cdot 02 \times 10^{-6}$ candles at one metre as the limit of visibility for direct vision. Their later results‖ *seem to indicate* that the total flux is cumulative up to about 10′ of an arc; this result is in accordance with observations of Loeser¶ extending to 8′ of an arc, but it is not altogether in agreement with those of Ricco¶ and Charpentier¶, who both consider that the effects are cumulative over the whole foveal area of about 50′. An explanation of this discrepancy, suggested by Abney's results**, is that Paterson's measurements were not made for the absolute limit of visibility but for a match against a faint object (see below). Paterson and Dudding found (loc. cit.) that beyond the limits of 10′ the total flux, when the visibility is equal to that of their comparison object, varies directly as the linear dimensions of the source; i.e. the illumination multiplied by the linear dimensions of the source is constant. Piper†† shows that the last result holds good for the dark adapted periphery, when the areas are sufficiently large; later investigations indicate that his results do not apply for small areas. Abney's results‡‡ show that there is no cumulative effect beyond 4°, so that the extinction values are as follows for the wave-length 530 $\mu\mu$:

* See Tscherning, *Physiologic Optics* (English Translation), 231.
† *Researches in Colour Vision and the Trichromatic Theory* (1913), 165, 166.
‡ Abney, *loc. cit.* 174. § Optical Convention (1912).
‖ *Illuminating Engineer* (May 1915), 210.
¶ For references and abstract see Parsons, *Colour Vision*, 120 and 118.
** Abney, *loc. cit.* 183.
†† *Z. f. Psychol. u. Physiol. d. Sinnesorg.* 32 (1903), 98.
‡‡ Abney, *loc. cit.* 171.

Table I.

Size of object	Relative illumination for extinction
4° 11′	6·6
1° 3′	19·5
31′	63

that is, the reduction beyond 1° 3′ is 1/3. The reduction from 31′ to 1° 3′ might be explained on the basis of reduction $\frac{60}{91} \times \frac{63}{91}$, that is, the effect is completely cumulative up to 50′ and then varies as the linear dimensions, probably up to about 3°. Abney states that for smaller objects the results are well represented by a reduction of illumination of 10 for a reduction of area of 16.

It is interesting to compare the absolute values as given by Abney and Paterson. Abney's results give 96×10^{-6} candle metres as the minimum illumination and this is multiplied by 10 for an object of 31′ diameter. This is equivalent to:

$$96 \times 10^{-6} \times 10 \times \frac{31}{3400} \times \frac{31}{3400} \times \frac{\pi}{4} \times \frac{1}{\pi}$$
$$= 2 \times 10^{-8} \text{ candles at 1 metre,}$$

which is the value given by Paterson.

Abney gives (*loc. cit.* p. 183) a most instructive comparison between the visibility of discs subtending angles of 1° 57′ and 10′ 46″ respectively. The discs are illuminated equally and the illumination increased till they are equally bright, and the illumination recorded. The illumination on the larger disc is then reduced to one-half and the illuminations reduced together till they again appear equally bright. The Table shows Abney's results, the ratio of the illuminations on the two discs being explicitly given; an additional column has been calculated, showing in each case the area on which the quantity of light, which is necessary to show the 10′ 46″ aperture, has been concentrated.

Table II.

Ratio of illuminations	Log. illumination on smaller	Log. illumination on larger	Log. ratio of illumination of smaller to extinction value	Area over which "extinction light" is spread
1	3·66	3·66	2·58	33″ sq.
1/2	3·05	2·75	1·97	67″ sq.
1/4	2·54	1·94	1·46	120·3″ sq.
1/8	1·94	1·03	·86	240″ sq.
1/16	1·42	·22	·34	436″ sq.
1/32	1·16	− ·34	·08	589″ sq.
1/52·5 (Extinction)	1·08	− ·64	—	—

It will be noticed that the two areas show the same brightness for the same illumination, if *at least the extinction quantity of light* be concentrated on the unit area represented by one cone. The illumination for which the two areas are equally

bright is about 2 metre candles. When the illumination is reduced to 1/4 this quantity of light is spread over an area four times as large in the smaller and eight times in the larger.

The Table also shows that when the visibility of the two objects is greater, the effect of increased area is less. To obtain equal visibility at higher illuminations, the ratio of the illumination on the smaller disc to that on the larger may be decreased. The Table enables us to find, by interpolation, this ratio for any assumed illumination on the smaller disc. If the illumination on the smaller disc be taken to be four times the extinction value, the logarithm of the ratio becomes 1·07 instead of 1·72 for the extinction value. The value 1·72 is consistent with the hypothesis that the minimum illumination for visibility is determined as follows: Up to an area of about 50′ square the total flux must be equal to a definite quantity, viz. that given by $\cdot 02 \times 10^{-6}$ candles at 1 metre, but when the area exceeds this value the total flux varies directly as the linear dimensions of the object. The value 1·07 is consistent with Paterson's result, viz. that for equal visibility with a small source, whose candle power is equal to about four times the minimum visible source, the total flux is constant up to an area of about 11′ square and then varies as the linear dimensions. Paterson's arrangement practically ensured that the eye should not adapt itself either by pupil changes or by variation of retinal adaptability during the tests.

The variation of pupil with illumination is of considerable importance in this connection, and for the illuminations we will be considering it may be represented approximately by considering that an increase of the illumination of ten times will correspond approximately to an increase of the quantity of light entering the eye of eight times. If this allowance be made, the unit area of Table II, when the two objects appear of the same brightness for the same illumination, would be 25″ square, which corresponds very closely to the area occupied by a single cone at the fovea.

Extinction of Colour.

When the illumination is reduced the colour will disappear before the extinction of the light. Abney's results on the extinction of colour show that: (1) the illumination at which colour disappears has a minimum value of about ·0025 metre candle for wave-lengths about 470 $\mu\mu$, the size of the patch of light being about 1° 30′; another observer gives ·0012; (2) the illumination at which the loss of colour takes place may be increased ten times if the linear dimensions of the object be increased eight times. The latter result suggests that, when an allowance is made for the effect of pupil changes, the illumination varies inversely as the linear dimensions. Using Abney's values and extrapolating for smaller apertures, the illumination necessary for the recognition of colour on a patch of $\frac{1}{2}$′ square would be approximately 2 metre candles, being approximately the same as for the recognition of the actual brightness of an object.

Paterson's results suggest that for the recognition of light the illumination multiplied by the area is constant up to a definite angular size and that beyond

this size it is the linear dimension multiplied by the illumination that remains constant. We have seen that the boundary value of 10′ given by Paterson is probably determined by the actual quantity of light used, and that by still further reducing the comparison source the value would probably be extended to the foveal area.

The general conclusion is that the eye is capable of adding up the effects in various ways; (1) For *the recognition of true intrinsic brightness* of the object, the quantity of light necessary for recognition of light must be concentrated on the area of a single cone. (2) For the *recognition of colour* the effect of increased area is that the illumination multiplied by the linear dimensions is constant; while the illumination so calculated for the area of a single cone is that necessary for the recognition of the intrinsic brightness. (3) When necessary for the *recognition of light* the total quantity of light may be added up for areas not greater than about 50′ square, and the quantity so received is about $\cdot 02 \times 10^{-6}$ candles at 1 metre. When the area exceeds 50′ square the total quantity of light necessary for recognition varies as the linear dimensions of the object up to about 3°.

It should be pointed out that these results are not in agreement with Abney's observations on the change of illumination with the area when the extinction value of the illumination is measured, although they are in agreement with the two sets of extinction values quoted above.

The results show that, after making the correction indicated above for pupil size, the illumination varies inversely as the linear dimensions to the power 3/2. No satisfactory explanation of this result can be given, and in view of the other observations it seems probable that some special conditions of adaptation or illumination have led to unusual results; this view is confirmed by the fact that Abney found the extinction values to be independent of the linear dimensions in one direction. For slits of constant length his results show that the illumination varies inversely as $b^{\frac{3}{2}}$, where b is the breadth of the slit, and the same allowance as before has been made for pupil changes. This last result may be explained by assuming that the unit square over which the total flux is to be calculated is the largest available square, viz. b^2, and that the allowance for the length of the slit l is made by multiplying the flux over the area b^2 by the quantity $\left(\frac{\text{total area}}{b^2}\right)^{\frac{1}{2}} = \left(\frac{l}{b}\right)^{\frac{1}{2}}$. Thus $Ib^2 \times \frac{l^{\frac{1}{2}}}{b^{\frac{1}{2}}}$ must be constant, or $Ib^{\frac{3}{2}}$ is constant, where I varies as the illumination. In other words the unit square is b^2 and above this the total flux required varies as the square root of the area. This is in accordance with the hypothesis (3) above, except that the square root of the area is substituted for the linear dimensions.

The idea that the area over which the effects are cumulative depends on the greatest illumination in the field receives considerable support from Abney's observations on the effect of general illumination on extinction values. Abney has measured the effect of the general illumination on the quantity of light required for recognition of light; this effect is due to two causes, viz. the reduction of the pupil size and the reduction of the area over which the light received is cumulative.

When the general illumination in the field was increased, the illumination

required to render visible a disc of 1° diameter was determined. With a general illumination of two candle metres the value was found to be roughly 100 times the minimum value for the case where there was no general illumination in the field. For the above illumination the flux corresponding to $\cdot 02 \times 10^{-6}$ candles at 1 metre is received on an area of about 40″ square, and we may assume that the eye adapts itself so that the flux is cumulative over this area, but that above this area the illumination required for visibility varies as the linear dimensions of the object. On this assumption the illumination for visibility would be 50′/40″ times the minimum; i.e. about 75 times the minimum, or making allowances for the change of pupil size approximately 120 times the minimum, which is in sufficiently good agreement with the observations*.

When comparisons are made with other values of the general illumination, in the part of the spectrum to which the eye is most sensitive, it will be found that quite roughly the extinction value is doubled when the general illumination is multiplied by four. These results do not hold even approximately towards the ends of the spectrum, the extinction value increasing more rapidly towards the blue and less rapidly towards the red. The behaviour at the red end of the spectrum is anomalous throughout, the quantities of light required for the recognition of colour of light differing much less than at other parts of the spectrum. The behaviour is such as to suggest that when the red sensation is stimulated there is also a sensation of light, but that the effects are cumulative only in the same way as the sensation of colour, i.e. the effects vary more nearly as the linear dimensions of the object.

In general the flux may be taken to be cumulative for the area on which the unit quantity ($\cdot 02 \times 10^{-6}$ candles at 1 metre) is spread and then is cumulative in proportion to the linear dimensions instead of the area.

The minimum illumination of about 96×10^{-6} metre candles corresponds to a very small amount of energy on each element of the retina.

The energy per square minute may be calculated to be 7×10^{-12} ergs per sec., if we assume a pupil size of 8 mm. and use Drysdale's value for the mechanical equivalent of monochromatic light. For dark adapted eyes the effect of a given light intensity increases with the duration of exposure up to 1/5 sec., and for values near extinction it is probable that this time increases. Taking 1/5 sec., the energy per square minute is $1 \cdot 4 \times 10^{-12}$ ergs, which is comparable with the "quantum" of energy for a wave-length $\cdot 5 \mu$, viz. $3 \cdot 6 \times 10^{-12}$ ergs. Thus the quantum of energy must be received on an area which does not exceed two or three square minutes. An experimental determination of the time required for recognition of brightness with the least illumination for central vision would be useful as it would give the area on which the quantum of energy must be received to give an impression of light.

Thus the visibility is limited by the necessity of concentrating this quantity of light on a sufficiently small element of the retina; it is also limited by the necessity of transmitting the record to the brain and this requires the reception of light

* This value is calculated for the part of the spectrum for which the extinction value is least.

corresponding to $\cdot 02 \times 10^{-6}$ candles at 1 metre. This is equivalent to about 8000 times the minimum quantity of energy per square minute and seems to be required for the transmission of the record.

Note. $\frac{96.10^{-6}}{\pi} \times \frac{\pi \times 16}{(1000)^2} \times \left(\frac{1}{3400}\right)^2 \times \cdot 005 \times 10^7$ ergs per sec.

where Drysdale's* value of the energy has been used; if the value given by Coblenz† be used the area should be 10 sq. minutes.

That the effect of the incident energy should be cumulative up to a certain area and then vary as the linear dimensions, will be readily understood from an electrical analogy. If energy were received by a group of thermo-junctions each connected to its own circuit, and each received an amount of energy U per sec., the voltage rise E would be $E = U/k$, where k is the constant of the thermo-junction; the current C in the circuit would be $C = E/R$, R being the resistance, and the energy would be $EC = U^2/kR$. If energy U_1 were distributed over a number n^2 of such junctions each circuit would have a voltage $E = \frac{U_1}{n^2 k}$ and the energy transmitted by each would be $\frac{U_1^2}{n^4 kR}$ while by the n^2 circuits it would be $\frac{U_1^2}{n^2 kR}$. So that in order to produce the same effect it would be necessary to have

$$\frac{U_1^2}{n^2} = U^2 \text{ or } U_1 = nU.$$

In other words the total energy required would vary as the linear dimensions of the receiving area, or the illumination required would vary inversely as the linear dimensions. If, however, the receivers were connected in series, the voltage effects, and therefore the energy, would be almost strictly cumulative.

The effects described for the eye would occur if the various receiving circuits were arranged to collect the energy in the same way as a set of receivers in series, but as soon as there is recognition of light the receivers are subdivided in a manner depending on the greatest illumination in the field. This subdivision continues as long as the necessary quantity of light is received to transmit the message, each group of receivers collecting its own energy and "sending" by its own circuit, the message being recorded by the energy sent by all the groups. When the receiving group is reduced to one element, perception of colour is possible, and when the message can be sent by *one element alone*, recognition of intrinsic brightness independently of the area becomes possible.

Visual Acuity and Brightness.

It is common experience that visual acuity depends on the illumination. Since a certain amount of light is necessary to produce the sensation of light, it seems obvious that detail cannot be recognised unless each element of the detail sends to the eye sufficient light for its recognition. Drualt has made a series of observations

* Drysdale, *Proc. Roy. Soc.*, A, 80 (1907), 19.

† Coblenz and Emerson, *Bulletin of the Bureau of Standards*, 14, No. 305 (1917).

recorded in Tscherning's *Physiologic Optics*. The results are given in the following table; the first two columns are quoted from Tscherning* and the remainder have been calculated by the present author. The correction for pupil size is made as indicated on page 300.

Table III.

Illumination I	Acuity A	I/A^2	Candles per unit square of chart	Corrected for pupil size
0·016 metre candles	$\frac{1.0}{9.0.0} = 0.075$	2·9	—	—
0·020 ,, ,,	$\frac{1.0}{1.4.0} = 0.15$	·89	$2.5 \ 10^{-8}$	—
0·028 ,, ,,	$\frac{1.0}{7.0} = 0.21$	·62	$1.74 \ 10^{-8}$	$1.74 \ 10^{-8}$
0·047 ,, ,,	$\frac{1.0}{5.0} = 0.30$	·52	$1.45 \ 10^{-8}$	$1.30^2 \ 10^{-8}$
0·12 ,, ,,	$\frac{1.0}{2.7} = 0.37$	·85	$2.35 \ 10^{-8}$	$1.76 \ 10^{-8}$
0·25 ,, ,,	$\frac{1.0}{2.0} = 0.50$	1·00	$2.8 \ 10^{-8}$	$1.82 \ 10^{-8}$
0·67 ,, ,,	$\frac{3.0}{4.0} = 0.75$	1·18	$3.3 \ 10^{-8}$	$1.75 \ 10^{-8}$
1·50 ,, ,,	$\frac{1.0}{1.0} = 1.00$	1·50	$4.2 \ 10^{-8}$	$1.89 \ 10^{-8}$
16·7 ,, ,,	$\frac{1.0}{0.8} = 1.25$	—	—	—
5400 ,, ,,	$\frac{1.0}{1.0} = 1.50$	—	—	—

It will be noticed that apart from the one value these results show remarkable agreement with Paterson's value for the minimum source of light; that they are rather lower is partly due to the fact that the values are reduced to a pupil size corresponding to a lower degree of illumination. It will be noticed that the illumination must be more rapidly increased beyond 5′ of arc; this is partly due to the fact that the recognition is of Snellen's chart, in which the length of the whole letter is five times the unit length in the chart.

Observations have also been made by Koenig on the relation of illumination to acuity. Table IV shows corresponding values for his results; the numerical values are not strictly comparable owing to differences of conditions. The results show that for illumination-values of from ·03 to 2 metre candles the quantity of light received from the element recognised is the important factor; for smaller illuminations other conditions apparently affect the visual acuity.

Table IV.

Illumination I	Visual acuity A	I/A^2	Illumination I	Visual acuity A	I/A^2
·00036	·031	·375	·0048	·077	·81
·00037	·046	·175	·0080	·088	1·0
·00037	·038	·256	·0086	·088	1·10
·00038	·038	·26	·0091	·096	·99
·00063	·046	·31	·0096	·092	1·10
·00087	·055	·29	·010	·096	·96
·0013	·055	·43	·012	·092	1·4
·0022	·077	·36	·013	·088	1·7
·0023	·062	·60			
·0034	·092	·40	·032	·123	2·1
·0034	·062	·89	·035	·123	2·3
·0043	·062	1·1	·037	·132	2·1

* Tscherning's *Physiologic Optics*, 282.

Table IV (*continued*)

Illumination	Visual acuity		Illumination	Visual acuity	
I	A	I/A^2	I	A	I/A^2
·051	·154	2·1	·44	·400	2·75
·068	·154	2·8	·50	·462	2·4
·069	·176	2·2	·52	·462	2·4
·11	·185	3·2	·67	·523	2·1
·12	·242	2·1	·88	·558	2·9
·13	·205	3·1	·91	·615	2·4
·15	·231	2·8	·95	·538	3·3
·15	·205	3·6	·99	·500	4·0
·15	·231	2·8	1·00	·596	3·0
·16	·200	4·0	1·03	·558	3·2
·18	·246	3·0	1·03	·692	2·2
·20	·231	3·8	1·16	·564	3·8
·22	·308	2·3	1·19	·596	3·4
·22	·262	3·3	1·38	·615	3·5
·22	·308	2·3	1·76	·692	3·6
·22	·277	2·9	2·14	·744	3·9
·24	·269	3·3	2·20	·795	3·5
·28	·286	3·4	2·28	·923	2·7
·29	·308	3·1	2·37	·744	4·3
·34	·346	2·8	2·97	·667	6·7
·35	·320	3·4	3·95	·769	6·6
·36	·338	3·2	4·64	·654	11
·36	·358	2·8	6·06	·846	8·5
·41	·461	2·0	6·81	1·115	5·5
·41	·374	2·9	6·81	1·038	6·3
·44	·410	2·7			

On comparing this Table with Table III it should be noted that the unit area from which light is received is smaller in this case, being 50″ square, the approximate ratio of the two values of I/A^2 for the same illumination being 2·3 : 1, or, allowing for the difference in area of the element, 1·5 : 1. It will also be noticed that for small illuminations the values of I/A^2 depart in different directions.

Contrast in Illumination.

In order that contrast shall be detected it is necessary that the difference in illumination be at least ·5 % of the actual illumination. But if this illumination falls below a certain value the fraction increases. This is due to the necessity for a certain minimum quantity of light to produce any effect. The effect of any additional illumination will be cumulative over a considerable area, but *only as the linear dimensions above the area for which the normal illumination is effective.* Thus if the actual illumination be such as to define minutes, the additional light will be cumulative over an area of about 180′, so that the additional fraction of the illumination which can be detected is about 1/180; as the illumination decreases

below this value the area which is defined will vary inversely as the illumination, and the ratio will vary approximately as $I^{-\frac{1}{2}}$. Thus at ·25 metre candles the fraction would be about 1·1 %, at ·12 metre candles about 1·6 %, and at ·03 about 3·2 %. These values are intermediate between those given by Broca and Dow. The effect of increase of the pupil size with the decreased illumination should make the falling off somewhat slower.

Resolution of the Eye.

Regarded as an optical system of 5 mm. aperture, the eye should be able to resolve objects about 25″ apart, but the coarseness of the retina will modify this value. The following considerations will indicate the nature of the effect to be expected. Fig. 1, which is taken from Lord Rayleigh's *Collected Papers*, vol. IV, p. 246, shows the value of the light intensity when two small sources of light are

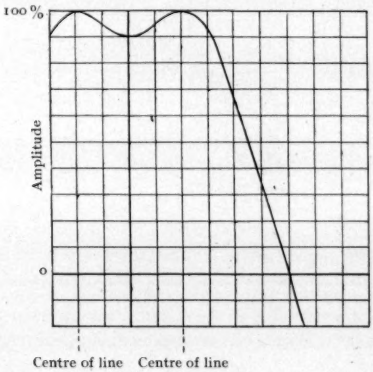


Fig. 1.

separated by an angular value which $= \lambda/a$, a being the breadth of the aperture supposed rectangular, λ the wave-length, and the two objects being self-luminous. If the angular width of the receiving screen be λ/a, the amount of light received on this screen will be a maximum for the central position and there can be no resolution. If the width of the receiving screen be reduced to $3/4.\lambda/a$ the amplitude will be increased about $2\frac{1}{2}$ % by moving from the central position, and the energy by about 5 %. If the receiver be reduced in width to $\frac{1}{2}$ the space, the difference in amplitude is about 1/15, i.e. the difference in intensity becomes 13 %. So that by magnifying the image of the two points two times, thus reducing the relative size of the receiver, the actual resolution of the system is improved. In the case of the eye an effect of this type may be partly responsible for the resolution limit being greater than the resolution limit of the optical system alone.

Accuracy of setting on an Object.

A setting is often made in an optical instrument by matching the quantities of light received from two bright objects; for example, when a scale division bisects the area between two cross lines we make the two areas give us an equal amount of light. The choice of width of object and illumination will be determined by the considerations given above as to the way in which light effects add up. If the light be sufficient to recognise the intrinsic brightness of each part, we appreciate the difference of area, but if the light be not sufficient for this purpose, we appreciate the effects of a difference in area by the apparent difference of brightness.

In "coincidence" adjustments we set by comparing the quantity of light received on the element of the retina with the quantity which would be obtained in the second field, and the sensitiveness is determined by the movement that may be made before it is possible to detect a change of illumination. The simplest

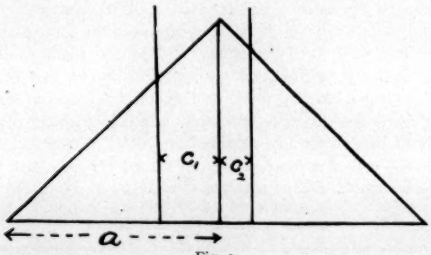


Fig. 2.

case to consider is that of a line where the intensity of the light falls off uniformly on each side through a width a (Fig. 2). If the illumination be recorded on a strip of width $C_1 + C_2$ which may be displaced from its central position, and if C_1 and C_2 be the parts on either side of the centre, the illumination is proportional to

$$C_1 - \frac{1}{2}\frac{C_1^2}{a} + C_2 - \frac{1}{2}\frac{C_2^2}{a} \quad \text{or} \quad C_1 + C_2 - \frac{1}{2}\frac{(C_1^2 + C_2^2)}{a},$$

or

$$C_1 + C_2 - \frac{1}{a}\left\{\left(\frac{C_1 + C_2}{2}\right)^2 + \left(\frac{C_1 - C_2}{2}\right)^2\right\}.$$

Thus the loss when $C_1 \neq C_2$ is $\frac{1}{a}\left(\frac{C_1 - C_2}{2}\right)^2$,

and this represents a fraction of the whole illumination received equal to

$$\frac{\frac{1}{a}\left(\frac{C_1 - C_2}{2}\right)^2}{C_1 + C_2 - \frac{1}{a}\left(\frac{C_1 + C_2}{2}\right)^2}, \text{ i.e. } \frac{(C_1 - C_2)^2}{(C_1 + C_2)\left(\frac{a - (C_1 + C_2)}{4}\right)}.$$

Thus the fractional loss is the product of the two factors:

$$\frac{\text{displacement}}{\text{width of receiver}} \text{ and } \frac{\text{displacement}}{\text{width of blurring beyond receiver}}.$$

The least displacement is given by d where

$$\frac{d}{2C} \cdot \frac{d}{a - \frac{C}{2}} = \cdot 0055.$$

If $d = xa$ we have

$$x = \cdot 07 \left(\frac{2C}{a} \frac{a - \frac{C}{2}}{a} \right)^{\frac{1}{2}}$$

subject to C being less than a. If $C = a/2$

$$x = \cdot 07 \times \cdot 85 = \cdot 06$$

that is, the displacement of 1/8 of C will be appreciated.

Considerations of the same character will apply to the case of a line object when the blurring due to diffraction is taken into account. Approximately accurate results may be obtained if we consider that diffraction effects produce a uniform blurring. We consider the diffraction pattern of a line to be sufficiently closely represented by a uniform blurring out over a width of $2a$, the line having a breadth of $2b$, and the receiver a width of $2c$; the effect of a displacement from the position of maximum effect can be readily obtained.

If the width $b - a$ be less than c, we can set on the line, and the results are analogous to those above, except that the displacement fraction is

$$\frac{d^2}{2a \cdot 2c - c^2 + (b-a)(2c-(b-a))}$$

and this is less sensitive than for a *thin line*. But if $b - a > c$ *the setting can be made on the edge*. In this case the change is $\frac{d^2}{2} \Big/ 2c \cdot 2a$,

i.e.
$$\frac{d^2}{8ac} = \cdot 005,$$

or
$$\frac{d}{a} \cdot \frac{d}{c} = \cdot 04.$$

If $a = 2c$ we have
$$\left(\frac{d}{2c}\right)^2 = \cdot 02,$$

$$\frac{d}{2c} = \cdot 14,$$

or
$$d = \tfrac{1}{7} \times 2c = 3'' \text{ approx.}$$

In general a will be somewhat larger and the sensitiveness will be somewhat less. The more exact consideration of the diffraction diagram will modify these numerical results but the general character of the effects will be of the order given above.

Mr W. H. A. Fincham has been good enough to compute and draw for me the

case of a line of 75″ width as seen by an optical system resolving 25″ which has a receiver 25″ wide. Figs. 3 and 4 show the results; it will be seen that a movement of about 2½″ corresponds to a change of intensity of about 1 % as the receiver is moved from the edge of the line, and this may be regarded as the limit of accuracy

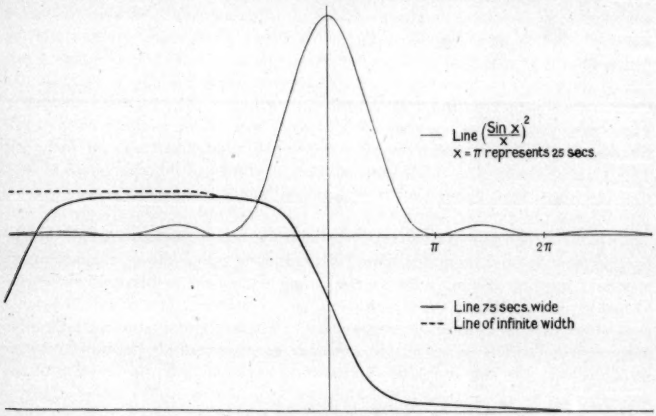


Fig 3. Diagram of intensity.

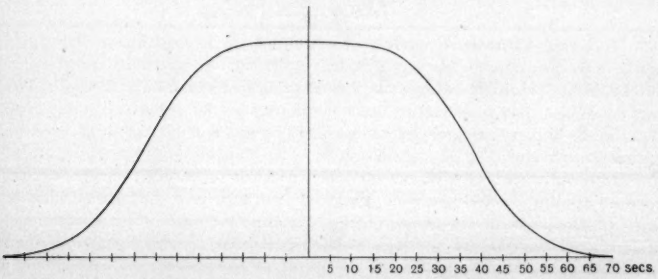


Fig. 4. Diagram of intensity as received by a receiver 25 secs. wide from a line 75 secs. wide.

in setting on the edge. Such a setting could only be made after a considerable amount of training with an instrument and under ideal conditions. It is such a setting that is used for a coincidence adjustment in a range-finder, the edges of two lines, which meet at their ends, being compared. The probable error is about $2{\cdot}5 \times \sqrt{2} = 3{\cdot}5$ seconds. It is interesting to compare this accuracy with

the results given by Baker and Bryan from direct experiment on coincidence adjustments, with both sides of the line available for observation; they give for the best observers using broad lines, 6″, 5″, 4″, 7″, 2·2″, 6″, 5″, as probable errors. (Opt. Convention, 1912, p. 257–9.)

The same diagram could be used for considering the case of a "bisecting" adjustment, i.e. a setting in which a scale-line is placed evenly between two other scale lines; in this case, however, the width of one white space is noted and the width compared with that of the other white space. The accuracy of setting the eye on each edge of the white space is of the same order as above, viz. 2½″. As there are really four settings, the probable error is 2 × 2½″, but this is twice the displacement of the line, so that the probable error in the position of the scale should be 2½″. The probable errors given by Baker and Bryan are 3·3″ and 3·1″; 7·6″, 11·2″, 8·1″, 15·5″, for different observers. Settings of this character are only possible when the illumination is sufficiently high to make the recognition of true intrinsic brightness possible.

It is the recognition of these small variations of brightness that enables the eye to recognize the position and shape of the boundaries of an object; the movement necessary to bring this boundary to the centre of the field is sufficiently sensitive to enable us to appreciate the movement if we can appreciate the change of brightness which enables us to set on the boundary. The recognition of these muscular movements and their use to enable us to associate the complex optical image of an object with its other properties depend to a large extent on the training of the eye.

DISCUSSION

Mr Lionel Laurance congratulated the author on having thrown light on a rather obscure subject. No very definite results had been obtained with regard to the limits of visibility owing to the different conditions under which experiments on the subject had been carried out. In measuring the visibility of black type on a white background, the cleanliness, quality, etc., of the background must be taken into account.

He thought that experiments on visibility failed to be exact chiefly because one does not know enough about the mind which governs the phenomenon of vision. The limits would depend on the kind of people making the observations, as a trained observer can see objects which cannot be detected by an untrained one.

Mr P. F. Everitt enquired whether the experiments related to monocular or binocular vision. He asked what was the criterion in setting a vertical line on two oblique lines crossing at 45°.

Mr T. Smith said that with this type of setting one usually relied on obtaining the same amount of rounding off in the angles. He considered it was not a very good type.

Mr J. Guild (remarks partially communicated) said that the author had rendered

a useful service in investigating and co-ordinating the visibility data of different investigators. For instance he had explained why the limiting area for which different workers had found light to be cumulative differed as they did.

With regard to this question of accumulation, it was easy to see why, for the first part of the range, the effect should be proportional to the area, since this was simply a measure of the total light, but it was not easy to see a physical meaning for the range of partial accumulation in which the effect varied as the linear dimensions. How was this interpreted in the case of rectangular or irregularly shaped objects: was the effect in such cases proportional to the square root of the area?

Another point brought out by the author was that the perception of colour began at the same intensity of illumination as perception of intrinsic brightness; and that this corresponded to the reception of the threshold quantity of light on a single cone. He did not at the moment see a physiological reason for this, nor had the author advanced one, but the point was a most suggestive one.

He was interested in the variation of Fechner's fraction at low intensities. Many writers on physiological optics considered it necessary to evolve equations, photochemical and otherwise, to account for Fechner's Law by peculiarities of the visual receptor process. He had always held the view—as did Fechner himself—that this Law was purely psychological, and would hold absolutely for all ranges if the eye were such a simple organism that the amount of luminous sensation was strictly proportional to the intensity of the incident light; and that it was the departures from Fechner's Law at low and high intensities, rather than the Law itself, that required explanation*. Mr Chalmers has tackled part of the problem by giving an explanation of the departure at low intensities in terms of known visibility data.

He thought, however, that the author over-emphasised the importance of illumination in connection with the recognition of detail, as there were many other factors besides this which came into the problem. Investigations of the legibility of test type, while essential to a complete treatment of the subject, were likely to prove misleading if given too prominent a place, since a mere black and white diagram, in its freedom from shadows, etc., differed in many essentials from the great multitude of objects in which the eye was called upon to distinguish detail.

With regard to the accuracy of setting in optical instruments he was of opinion that the most important factor in every type of setting suitable for accurate work was the observer's sense of form-symmetry. The illumination had to be sufficient to avoid strain in seeing the object and cross-lines distinctly, while it should not be high enough to spoil the acuity of the eye by glare and irradiation effects; but there was a large range of brightness for comfortable working with any particular type of setting, within which the accuracy of the setting was quite independent of the brightness. If the author's theory that the accuracy of setting depended on the appreciation of small differences in the light received from the two sides

* See *Proc. Phys. Soc.* 29 (1917), 354.

of the setting were correct, a highly skilled photometrician should automatically become skilled in—say—spectroscopic settings, and vice versa. It was, however, a matter of common experience that this is not the case, but that separate training is required to develope accuracy in either class of observation. Moreover, the fact that more comfortable and accurate settings can be made on a spectrum line—or any other line—with diagonal cross-lines than with a single cross-line brought into coincidence with the line is readily explained by the greater facility with which a slight asymmetry can be noticed in the former case than in the latter; but, if the sensibility depended on the amount of light liberated on one side and obscured on the other by a slight error in the setting, the accuracy should be much greater in the second case since the effect will be at least partially accumulative along a considerable part of the line; whereas with diagonal cross-lines we are dealing with a very small region of the line in the neighbourhood of the intersection of the cross-lines.

Mr T. Smith described results he had obtained in experimenting with Hunter's definition testing apparatus, which appeared to yield strong evidence that the accuracy of setting falls off as the illumination is increased beyond a certain amount. At higher illuminations the difference of illumination mentioned would probably not suffice for the recognition of detail.

Mr J. Rheinberg remarked that the "recognition of detail" was a subject on which much had been written and much more could be said; he was all the better pleased to find that Mr Chalmers had given them an extremely interesting lecture which to his mind did not deal with the recognition of detail at all, but with subjects on which far less had been written and collated, viz.: the limits of, and differences in, the visibility of illuminated areas, and the limits of accuracy in setting with certain classes of optical instruments. As a microscopist, he thought the word "detail" must be confined to differentiated elements in the structure of objects themselves, and could not be used in the sense of luminosity differences in the parts of optical images of undifferentiated structures or their boundaries, which were caused by the instrument itself or by the eye. Otherwise we might easily arrive at confusions and might, for example, find ourselves discussing the "detail" of ultra-microscopic particles.

With regard to the interesting diagrams of luminosity curves exhibited, it required, he thought, to be borne in mind that these represented one specific case only, viz.: that of perfectly opaque lines seen against a field of some particular degree of brightness. If the field brightness were varied, if the lines were semi-transparent, transparent, or coloured, or if the lines were upon a dark field, etc., then the luminosity curves would undergo modifications.

Major E. O. Henrici said that in setting a thick line between two thin ones the thickness of the line did not matter very much so long as the edges of the lines were sharp. The thick line should nearly fill the space between the thin ones. One of the most accurate methods of setting was to set a thick line on a circle whose diameter was about three times the thickness of the line.

This was the first occasion on which he had heard the statement that a setting

could be made to an accuracy of $2\frac{1}{2}''$. Text-books usually stated the angle was very much greater, their values being in his experience undoubtedly much too high.

Instructor-Commander T. Y. Baker said that before the last Optical Convention he had carried out experiments on settings of different types. He had found great differences in the accuracy obtained. In some types the eye could not do better than $2'$ or $3'$ while with others an accuracy of $10''$ or $15''$ was easily obtained. In setting a thick line between two thin ones and in coincidence types he had found cases in which the probable error was $3''$ or $4''$. He had been told that Messrs Barr and Stroud have a worker who invariably sets to less than $4''$, and he thought that a trained observer could sometimes get lower than $2\frac{1}{2}''$.

He considered that the author's theory of vision would be capable of explaining a number of discrepancies in connection with experiments on visibility.

Mr L. C. Martin communicated the following remarks:

The suggestion of Mr Chalmers as to the possible explanation of the difference between the results of Paterson and Dudding and other experimenters, including myself*, seems hardly satisfactory. In a considerable number of my experiments the amount of light received from the test object was very considerably above true "threshold" values, owing to the presence of background which was more or less illuminated when the test-object became invisible. The marked difference in the nature of the results occurring at 1 degree as subtense for the test object persisted throughout the range of experimental work even when dealing with later objects, in which case to recognise the latter the illumination had to be well above that necessary to perceive light. These experiments, however, allowed the perception to take place away from the fovea, and consequently it does not appear that filling the fovea has anything particular to do with the change in the nature of results. In the work of Paterson and Dudding, however, when comparing two small test objects, it seems to me that in looking from one to the other foveal vision *would* be used, which seems to indicate a possible source of the discrepancy.

These subjects are of great importance and it is very difficult to correlate and even to ascertain the results which have been already attained. American experimenters have been very busy on this and kindred topics. Quite a number of results which will be of great interest to Mr Chalmers can be found in the *Psychological Review*. A Bibliography of such papers is very badly required.

The author, in reply to Mr Laurance, stated that in Tscherning's experiments the illumination of the white background had been measured.

Paterson's experiments were chiefly with monocular vision. For low intensities he had found that the effect of binocular vision was practically additive.

With regard to Mr Guild's question about rectangular areas Abney had carried out experiments on slits and had found that the effect was proportional to the square root of the area.

* Bulletin No. 3, Department of Scientific and Industrial Research, "Study of the Performance of Night Glasses."

He agreed that symmetry may have something to do with accuracy of setting, but he thought that sensitiveness to symmetry was dependent on the recognition of the boundaries and therefore on visibility. One more or less unconsciously looks from one element to another in judging symmetry.

He thought that the result obtained in Mr T. Smith's experiment could be explained by the assumption that it is difficult to detect small differences of illumination at high intensities.

In reply to Mr Rheinberg he stated that he had purposely not touched on a number of very interesting points. He had omitted, for example, all questions relating to differences in colour and those relating to all other than point sources.

In reply to Mr Martin's written communications the section of the paper on visibility had been written before the publication of Mr Martin's paper. The results given in the latter paper seemed to confirm the view that Abney's results as regards the effect of area on the illumination required for visibility could not be universal or even typical. The problem of non-foveal vision did certainly differ very much from that of foveal vision; the author suggests that in all experiments on the recognition of detail at low illuminations, comparison observations on the visibility of corresponding sources of light should be made.

DESCRIPTION OF THREE GERMAN NAVAL GUN-SIGHTING TELESCOPES

By JOHN S. ANDERSON, M.A., B.Sc., Ph.D.
and A. BARBARA DALE

(From the National Physical Laboratory.)

MS. received, 11th June, 1919. Read, 12th June, 1919.

With the kind permission of the Director of Naval Ordnance, Admiralty, we are able to publish the following account of the detailed examination of three Zeiss Gun-Sighting Telescopes. The instruments are (1) a periscopic sight, (2) a right angle sight, and (3) a variable power sight.

(1) PERISCOPIC SIGHT.

The instrument is marked Carl Zeiss, Jena, 10·5 cm. Ubts. u. Tbts. K.L./45 (Ehrhardt) Nr. 108, 6 × 8·3° U.Z.C./12, 1687.

(A) Mechanical Properties.

General Characteristics. A photograph of the dissected instrument is shown in Fig. 1. The mechanical details of the instrument are shown in section in Fig. 2*. The telescope is designed to deflect the light twice through 90°, the optical axis of the eye-piece being parallel to, and at a distance of 5·5 cms. below, that of the objective. The lower portion 1*a* of the main casting 1 is dove-tailed and has three circular holes 1*b* drilled in it. The instrument is evidently fixed to the gun mount by means of this part of the casting.

Metals Employed. The lens cells, the collars used for securing the lenses in their cells, and the colour filter holder 5, as also the cover plate 6 and ring 7, are all made of hardened steel. There is a celluloid washer 8 between 6 and 7. The rest of the instrument is constructed from brass and gun metal.

Protection against Scattered Light. The inner surfaces of such tubes or portions of tubes as would give rise to scattered light in the system have fine screw-threads cut in them so as to diminish the amount of light reflected from them.

Water-tightness. The means employed for ensuring that the instrument should be quite water-tight are very thorough. They may be enunciated as follows:

(*a*) A glass window A, which is pressed against the objective end of the casting and is held in position by the cap 2, serves to protect the objective. Between the cap and the window a thin brass washer 9 and a canvas rubber washer 10 are introduced, and between the window and the end of the casting there is a rubber washer 11. There is a similar arrangement of washers 9′, 10′, and 11′ at the eye-

* For the purposes of reproduction the original drawings of Figs. 2, 6, and 9 have been greatly simplified. The necessary reduction in size has resulted in some of the details being slightly indistinct.

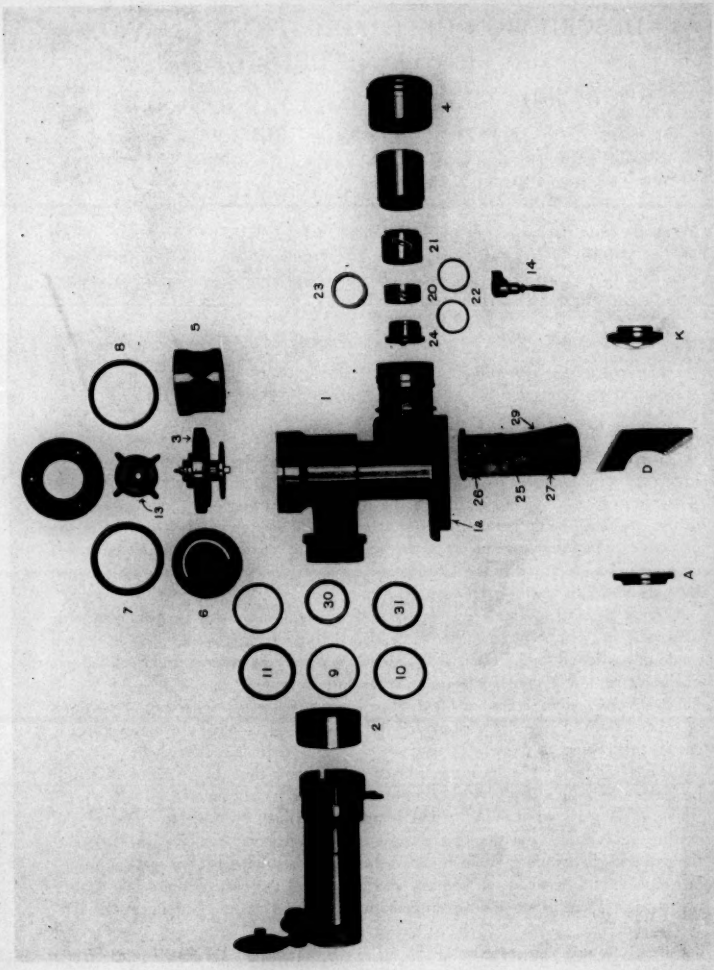


Fig. 1. Periscopic sight.

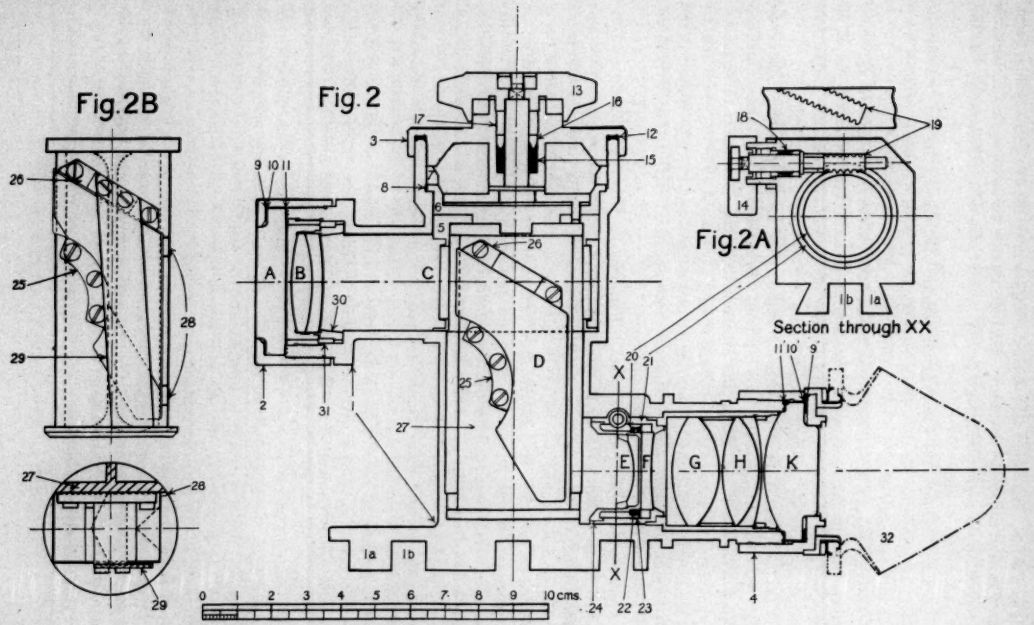


Fig. 2. Periscopic sight.

piece end of the instrument, the outside component of the eye-piece system being shaped so as to act also as a window. Further, there is a rubber washer 12 between the top end of the main casting and the cap which holds the mechanism for rotating the colour filter holder 5.

(*b*) Each end of the main casting against which a cap fits has two shallow grooves turned in it. As the rubber washers are pressed into these grooves, very good fits are obtained.

(*c*) There is a liberal supply of grease, the chemical constitution of which is given later, at the parts where the caps press against the windows and at all other important junctions. A thin coating of some substance like shellac had been painted on the grooved portion of the window A.

(*d*) To prevent the entrance of moisture at the handle 13 which rotates the colour filter holder and at the lever 14 (Fig. 2A) marked "Hell" and "Dunkel," reliance seems to be placed on the excellent fit of the spindles at these places. In the case of the former there is a leather ring 15 round the bottom of the spindle and above this there come a brass ring 16 and a brass nut 17. The spindle of the "Hell" and "Dunkel" lever is supplied with a leather ring 18 (Fig. 2 A) at the part where it bears on the main casting.

Lever marked "Hell" and "Dunkel." This lever 14 (Fig. 2 A) operates a worm-gear 19 which causes a cell 20 to move through a certain distance along the axis of the eye-piece system; a screw projecting from this cell is constrained to move in a diagonal slot cut in the cell 21, the direction and amount of the motion being governed by this slot. In a groove of the cell 20 at the end which is nearer to the eye-piece end of the instrument there are two small glass tubes 22 of circular cross-section and bent round in the form of rings. These tubes are held in position in the groove by a collar 23. The tubes are filled with a fine powder which proved to be a luminous compound having approximately the same luminosity as that given by the British ·2 mg. radium bromide per gr. compound. The luminosity was found to be 70 per cent. of the N.P.L. standard*.

The purpose of these tubes is to illuminate the cross-lines on the graticule lens F for use in connection with night-work. When the lever 14 is in the position where the word "Dunkel" (i.e. "Dark") is opposite the small arrow-head engraved on the top of the fixed collar below the lever, the cell 20 containing the tubes is in the position shown in Fig. 2. The light emanating from the tubes is then screened from the cross-lines by the collar 24 which holds the graticule lens F in position. When the lever is turned until the word "Hell" (i.e. "Bright") is opposite the arrow-head, the cell 20 is moved towards the eye-piece end of the instrument, so that the tubes containing the luminous compound come opposite the edge of F and serve to illuminate the cross-lines. The edge of this lens is polished.

Prism Mount. The details of the prism mount are shown in Fig. 2 B in elevation and plan (the top of the mount being supposed removed in the latter). The guide pieces 25 and 26 are held by screws passing through slotted holes; this allows of

* The luminosity test was carried out by Mr J. W. T. Walsh, M.A., M.Sc., of the Electricity Department

the preliminary adjustment of the prism. When this adjustment has been made, the positions of these guide pieces are fixed by pins passing through them and through the casting 27 to which they are attached. The face of the prism nearer to the eye-piece end of the instrument rests against two small projections 28 which are let into the casting. Four small pieces of paper are fixed to the casting where the prism rests against it, and the bar 29, which fits loosely at one end into a slot and is held at the other end by two screws, serves to hold the prism in position in the mount. This bar presses on two small cork discs which are glued to the prism.

Colour Filter Holder. One colourless glass C and three colour filters (green, orange, and neutral, the last-named being shown on the side of the mount opposite C) are fitted in bezelled mounts on a cylindrical holder 5 which can be rotated by the handle 13. The angle between the normals to the surfaces of adjacent filters is 60°. The correct position of the filter which is being used, namely, normal to the optical axis of the objective, is secured by a spring catch and slot arrangement under the handle 13.

Adjustment of Objective. The objective is held excentrically in its cell 30, and an excentric ring 31 which fits round the cell allows of the necessary adjustment of the objective.

Eye-piece Cap. The rubber eye-piece cap used with the instrument had been broken off, but it was probably similar to the one attached to the right angle sight.

Detachable Spray Excluder. A spray excluder, which can be attached to the objective end of the instrument, is provided for use with the sight. A similar attachment is described later in connection with the right angle sight.

*Chemical Constitution of Grease Employed**. Owing to the very small amount of the material available it was not possible to make a very complete examination and thus enable the constituents to be definitely and conclusively identified, but some information has nevertheless been obtained. The grease could be separated into two portions by treatment with petroleum ether, one portion being soluble and the other not. The soluble portion could be further separated by treatment with alcoholic caustic potash into a saponifiable, and a non-saponifiable, fraction. The former yielded a fatty acid with a melting point of 43° C., and the latter had the characteristic "bloom" of vaseline with a melting point of 31° C., which is also consistent with the view that it is this substance. The fraction left behind on treating the original material with petroleum ether proved to be soluble in hot alcohol and possessed the characteristic odour of beeswax. The grease, therefore, seems to consist of three constituents, namely, beeswax, vaseline, and some other fat which, from the melting-point of the fatty acid, may possibly be tallow or lard.

(B) Optical Properties.

A section of the optical system of the instrument is shown in Fig. 3.

Observations were carried out on the general optical behaviour of the instrument as a whole and measurements were made of the dimensions of the lens components,

* We are indebted to Mr W. H. Withey, B.A., of the Metallurgical Chemistry Department for undertaking the analysis of the grease.

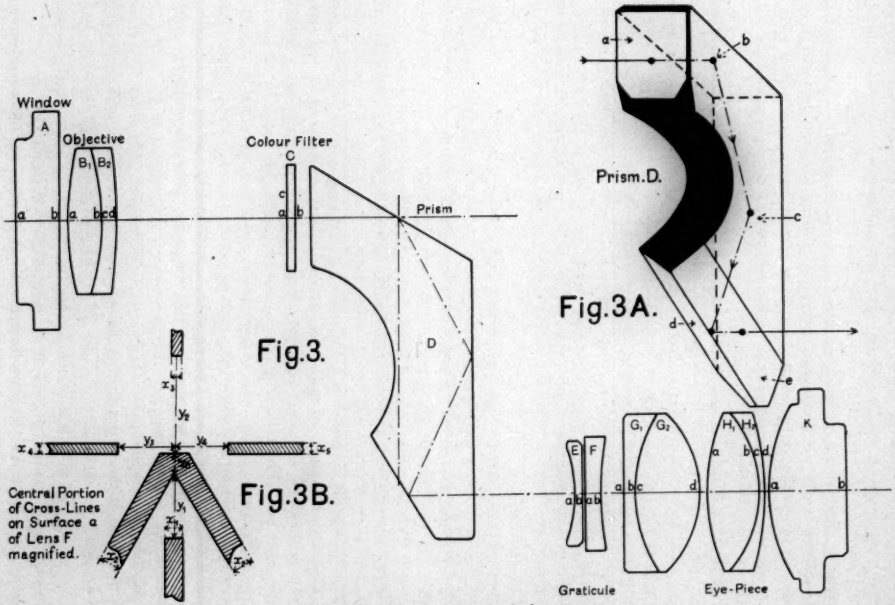


Fig. 3. Periscopic sight. Optical system.

their separations, the radii of curvature of the surfaces, the angles of the prism, the dimensions of the cross-lines, and the percentage transmission of the colour filters. Further, the refractive indices and dispersions of the glasses employed in the system were determined by means of an immersion method which one of us (J.S.A.) developed nearly three years ago. An account of this method will be given shortly to the Society. The results of the determination of all these optical data will now be described.

Power, Definition, etc.

Effective aperture of objective	2·8 cms.
Diameter of emergent pencil	·46 cm.
Magnifying power	6
Angular field of view	8·1°
Fraction of field over which the definition is good and there is freedom from colour	1/3
Colour in outer parts of field	Considerable
Percentage light transmission	35

Focus, which is fixed, is about ·5 D on the minus side of the position of best focus for normal vision.

Radii of Curvature. Dimensions of Lenses, etc.

All dimensions in cms.

Lens	Surface	Radius of curvature*	Axial thickness	Diameter	Approximate focal length	Separation
A	*a*	∞	·863	3·2, 4·3	—	A to B ·2
	b	∞	—	—	—	B to C 3·4
B_1	*a*	+ 7·31	·639	2·9	5·6	C to first surface of D 2·6
	b	− 4·93	—	—	— (12·3)	
B_2	*c*	− 4·92	·281	2·9	− 10·1	Last surface of D to E 1·95
	d	− 23·2	—	—	—	
C	*a*	∞	·155	2·1	—	E to F ·03
	b	∞	—	—	—	F to G ·45
E	*a*	− 2·08	·161	2·1	− 3·8	G to H ·06
	b	∞	—	—	—	H to K ·05
F	*a*	∞	·324	2·25	− 27·6	—
	b	+ 15·19	—	—	—	—
G_1	*a*	∞	·199	3·2	− 4·6	—
	b	+ 2·95	—	—	— (5·0)	—
G_2	*c*	+ 2·96	1·326	3·2	2·7	—
	d	− 2·18	—	—	—	—
H_1	*a*	+ 3·69	1·051	3·2	3·1	—
	b	− 2·50	—	—	— (5·6)	—
H_2	*c*	− 2·50	·139	3·2	− 6·2	—
	d	− 6·78	—	—	—	—
K	*a*	+ 3·36	1·552	3·47, 4·1	6·5	—
	b	∞	—	2·6	—	—

* Surfaces are considered positive when they are convex to the incident light (the light being supposed to enter the instrument at the objective) and negative when they are concave to the incident light.

Refractive Indices and Dispersions.

Lens	n_D	ν	Medium dispersion $C-F$	Partial dispersions $C-D$	$D-F$	Type of glass
A	1·510	63·7	·0080	·0023$_8$	·0056$_8$	Boro Silicate Crown
B_1	1·533	58·9	·0092	·0027	·0065	Zinco Silicate Crown
B_2	1·620	36·9	·0171	·0049	·0122	Ordinary Flint
D (Prism)	1·515	63·4	·0081	·0024	·0057	Boro Silicate Crown
E	1·550	52·9	·0104	·0030$_5$	·0073$_8$	Baryta Light Flint
F	1·551	53·9	·0104	·0030$_5$	·0073$_8$	,, ,,
G_1	1·647	33·9	·0191	·0054	·0137	Dense Flint
G_2	1·516	63·3	·0081$_5$	·0024	·0057$_8$	Boro Silicate Crown
H_1	1·516	63·7	·0081	·0024	·0057	,, ,,
H_2	1·649	33·8	·0192	·0055	·0137	Dense Flint
K	1·516	63·7	·0081	·0024	·0057	Boro Silicate Crown

Prism. The prism D in this instrument is of the "roof prism" type; it is designed to displace the optical axis parallel to itself through a distance of 5·5 cms. and to reverse the field. The prism is shown in Fig. 3 A. The light enters at the face *a* and is totally reflected internally at *b* and then at *c*. The light from one half of the field is then reflected from the face *d* to the face *e*, that from the other half of the field being reflected from *e* to *d*. The light then passes out of the prism at the face *c*. The path of the central ray is indicated in Fig. 3 A by means of the arrow-heads. In order to prevent overlapping of the two halves of the field the angle between the faces *d* and *e*, which form the "roof" portion of the prism, must be 90° to within a few seconds.

The angles between the faces are given in the following table, the results being accurate to about ± 2″ for the 90° angles and to about ± 5″ for the others.

Angle between	
a and *b*	59° 4′ 35″
b ,, *c*	120° 54′ 35″
a ,, *c*	179° 59′ 10″
c ,, *d*	52° 47′ 17″
c ,, *e*	52° 42′ 22″
d ,, *e*	90° 0′ 5″

Graticule. The cross-lines are engraved on the flat surface *a* of the lens F. An enlarged view of the central portion of the cross-lines is shown in Fig. 3 B. The arrow-head, which points upwards in the field of view, and the central limb of the arrow are about twice as thick as the other portions. The thicknesses and separations of the different parts are given in the following table:

	cm.
x_1	·0029 narrowing at edge of lens to ·0026 cm.
x_2	·0031
x_3	·0015
x_4	·0015
x_5	·0015
x_6	·0045
y_1	·0102
y_2	·0151
y_3	·0088
y_4	·0083

Angle of arrow = 61·5°.

Apart from the narrowing of the line whose thickness is x_1, no variation was found in the thickness of any of the lines greater than ± ·0001 cm.

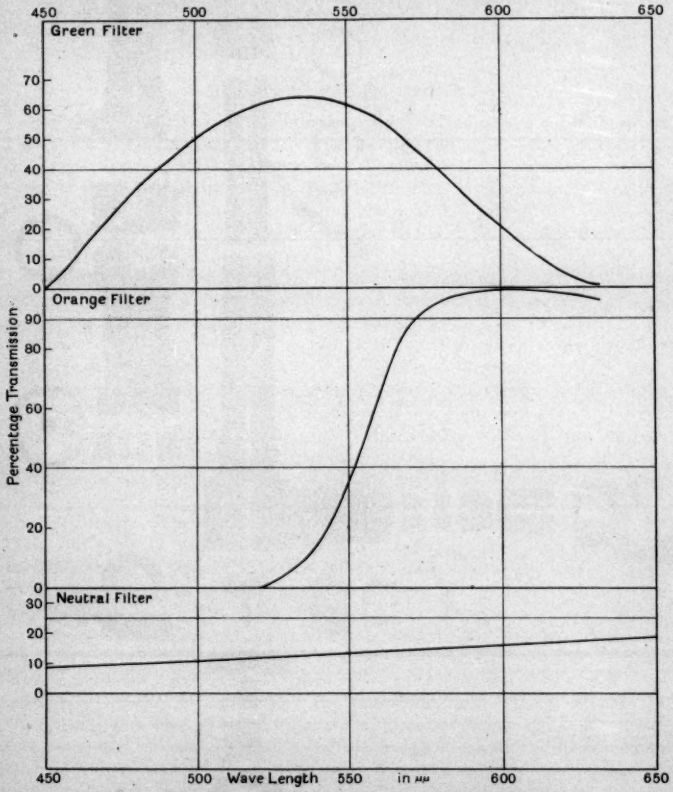


Fig. 4. Periscopic sight. Transmission curves of colour filters.

Colour Filters. The instrument is provided with three filters—green, orange, and neutral—and also a colourless glass of the same thickness. Spectrophotometric measurements of the percentage transmission of the three filters were made throughout the visible spectrum. The results obtained are shown graphically in Fig. 4.

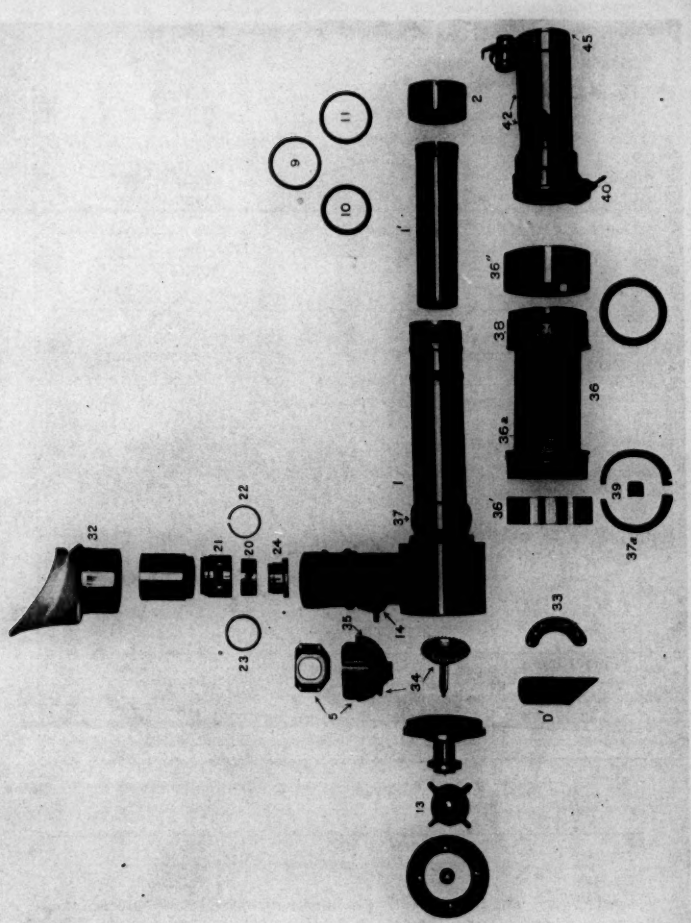


Fig. 5. Right-angle sight.

(2) RIGHT ANGLE SIGHT.

The instrument is marked Carl Zeiss, Jena, 10·5 cm. Ubts. u. Tbts. K.L./45 (Ehrhardt) Nr. 108, 6 × 8·3° U.Z. (s.E.) C/6, 1652.

(A) Mechanical Properties.

General Characteristics. A photograph of the dissected instrument is shown in Fig. 5. The instrument is very similar to the periscopic sight, so that the description of the mechanical properties of the latter applies also in almost every detail to those of this instrument. To facilitate matters the reference lettering in Fig. 6, which is a section showing the mechanical details of the right angle sight, has been made to correspond with that in Fig. 2, except that the optical elements are lettered A′, B′, etc.

The instrument is designed to deflect the light once through 90°. It is evidently for use in a position where the axis of the eye-piece makes an angle of 45° with the vertical, the eye-piece being directed upwards.

Reference will now be made to the chief points in which this instrument differs from the periscopic sight.

Objective Cell. The objective is held in position at the inner end of a tube 1′, which is screwed into the tubular portion of the main casting 1.

Water-tightness. Some moisture was found to have made its way into the space between the windows and the objective.

In connection with the spindle for rotating the colour mechanism the leather ring 15 is in this case placed between two brass rings 16 and 16′.

Prism Mount. There is no elaborate mount for the prism as in the previous case. The prism D′ was found to be simply glued to the base plate 33, and had no other method of support. There is evidence, however, to show that the prism should have been held in position by a strip attached by means of screws to the base plate 33.

Colour Filter Holder. Similar glasses to those in the periscopic sight are employed. They are fitted in bezelled mounts on the four sides of a square cylindrical mount 5 with rounded edges. The mount is rotated by means of bevel gear 34 by turning the handle 13. The side of the mount which contains the colourless glass is fixed by means of screws to the rest of the mount. It may therefore be removed to enable one to get at the screws which secure the casting 35 that holds the mount. Further, when the side is removed, the filter mechanism may be placed in position or removed from the instrument without disturbing the prism D′.

Collimation Adjustment. The connection of the outer tube 36 to the main casting 1 consists at one end of a ball and socket joint 37 while at the other end there are four adjusting screws 38 which press against flattened portions of the inner tube 1. These screws allow of the accurate adjustment of the direction of

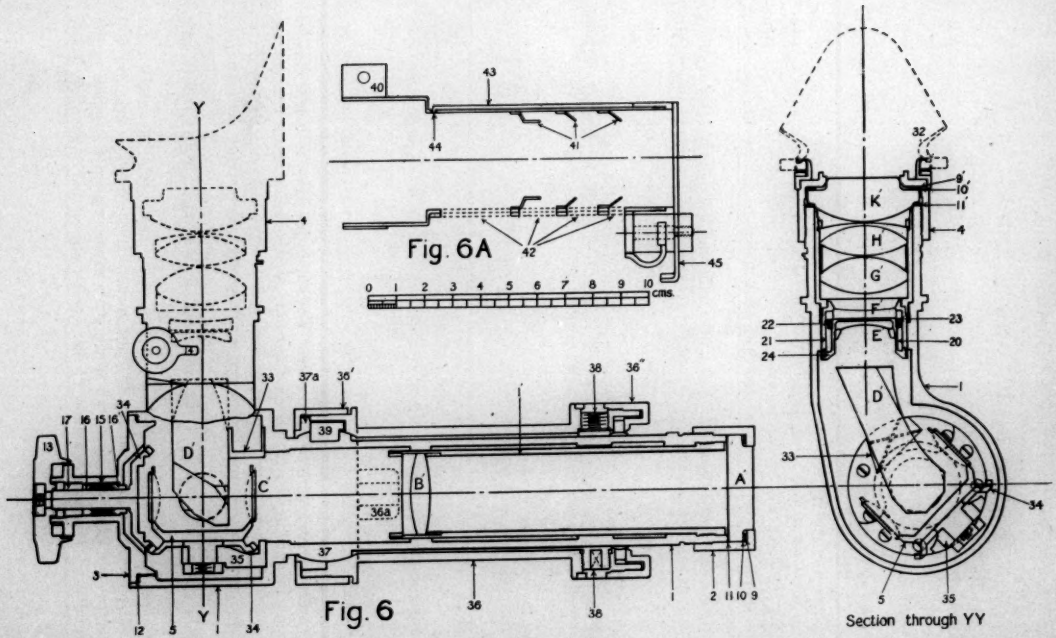


Fig. 6. Right-angle sight.

the optical axis of the system relative to the gun mount, to which the outer tube 36 is attached. In order to secure the correct relative orientation of the two tubes, a pin 39 fits into a hole in the ball 37 and into a groove in the outer tube. The two halves of a split ring 37*a* are held in position against the ball 37 by means of a cap 36′ which is screwed on to the end of the outer tube 36. The pieces of the split ring are shaped so as to fit round the pin 39. A second cap 36″, when screwed on to the other end of the tube 36, covers the four adjusting screws 38. When the cap is slightly unscrewed one can adjust the screws 38 through four holes in the cap. Two metal pieces 36*a* screwed to the tube 36 form a clip which has to do with the fixing of the instrument to the gun mount.

Eye-piece Cap. A rubber eye-piece cap 32 is used with the instrument. As can be seen in Fig. 6 the cap is of the asymmetrical type (i.e. it has a side flap), which is very much superior to the usual symmetrical type. The portion of the cap which comes next to the observer's nose is, however, rather thick for convenience in use.

Detachable Spray Excluder. A spray excluder can be attached to the objective end of the instrument. It is shown in section in Fig. 6 A. The attachment is made by means of a clamp 40. The diaphragms 41 serve to prevent water, etc. from reaching the window in front of the objective, and holes 42 are provided at the bottom of the tube to allow of water, etc., draining away. The outer tube 43 contains a similar set of holes; it may be rotated so as to close the holes in the inner tube. A spring catch and slot arrangement 44 serves to secure the outer tube in one or other of the two positions in which the holes in the inner tube are either open or closed. The spray excluder has a hinged lid 45 which may be closed when not in use.

(B) Optical Properties.

A section of the optical system of this instrument is shown in Fig. 7. The results of the determination of the optical data are as follows:

Power, Definition, etc.

Effective aperture of objective	2·8 cms.
Diameter of emergent pencil	·46 cm.
Magnifying power	6
Angular field of view	8·1°
Fraction of field over which the definition is good and there is freedom from colour	1/3
Colour in outer parts of field	Considerable
Percentage light transmission	38*

Focus, which is fixed, is about ·5 D on the minus side of the position of best focus for normal vision.

* This result was affected by the presence of a slight film of moisture on the inner surface of the window A′.

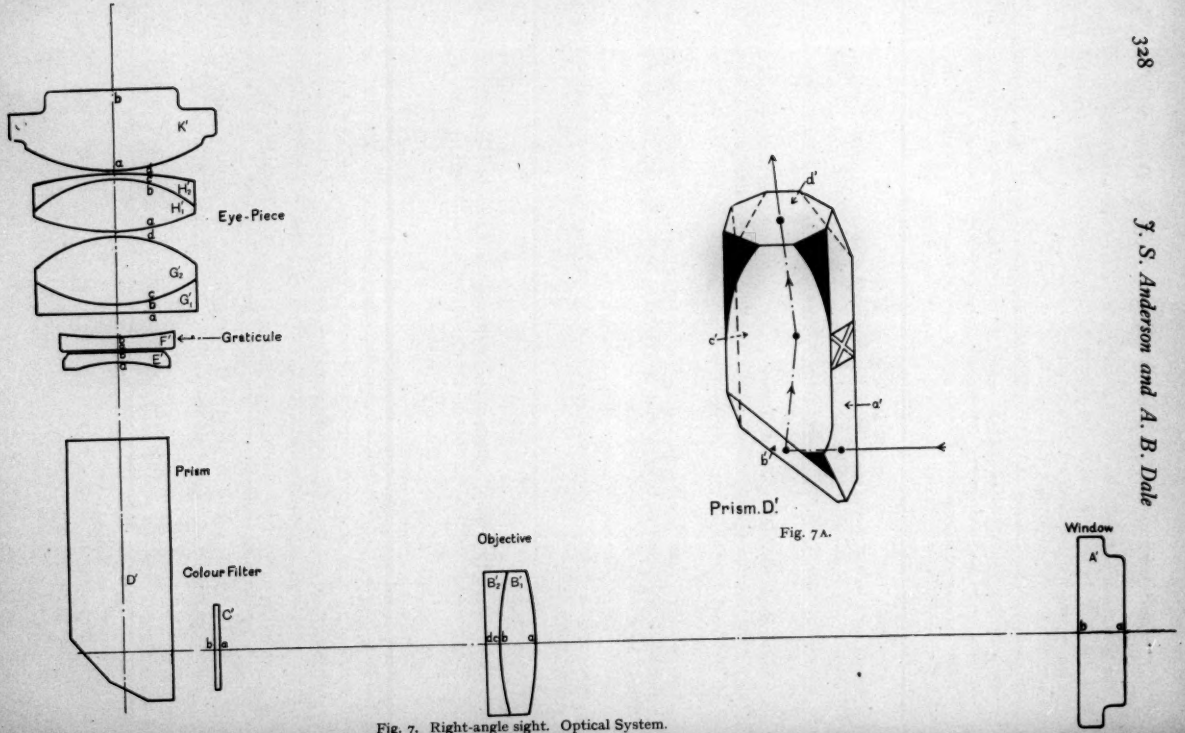


Fig. 7A.

Fig. 7. Right-angle sight. Optical System.

Radii of Curvature, Dimensions of Lenses, etc.

All dimensions in cms.

Lens	Surface	Radius of curvature*	Axial thickness	Diameter	Approximate focal length	Separation
A′	*a*	∞	·902	2·9, 3·8	—	A′ to B′ 10·6
	b	∞	—	—	—	B′ to C′ 5·4
B_1'	*a*	+ 7·32	·657	2·9	5·6	C′ to first surface of D′ ·71
	b	− 4·93	—	—	—	
B_2'	*c*	− 4·92	·287	2·9	− 10·2 } 12·3	Last surface of D′ to E′ 1·5
	d	− 23·3	—	—	—	
C′	*a*	∞	·147	1·8	—	E′ to F′ ·03
	b	∞	—	—	—	F′ to G′ ·45
E′	*a*	− 1·85	·129	2·1	− 3·4	G′ to H′ ·01
	b	∞	—	—	—	H′ to K′ ·01
F′	*a*	∞	·364	2·25	− 27·5	—
	b	+ 14·66	—	—	—	—
G_1'	*a*	∞	·190	3·2	− 4·6	—
	b	+ 2·95	—	—	— } 5·0	—
G_2'	*c*	+ 2·96	1·316	3·2	2·7	—
	d	− 2·18	—	—	—	—
H_1'	*a*	+ 3·69	1·051	3·2	3·1	—
	b	− 2·50	—	—	— } 5·6	—
H_2'	*c*	− 2·50	·169	3·2	− 6·2	—
	d	− 6·78	—	—	—	—
K′	*a*	+ 3·36	1·626	3·48, 4·1	6·5	—
	b	∞	—	2·6	—	—

* Surfaces are considered positive when they are convex to the incident light (the light being supposed to enter the instrument at the objective) and negative when they are concave to the incident light.

Refractive Indices and Dispersions.

Lens	n_D	ν	Medium dispersion *C*—*F*	Partial dispersions *C*—*D*	Partial dispersions *D*—*F*	Type of glass
A′	1·515	$63_{\cdot 5}$	·0081	·0024	·0057	Boro-Silicate Crown
B_1'	1·533	$58_{\cdot 0}$	·0092	·0027	·0065	Zinco-Silicate Crown
B_2'	1·618	$36_{\cdot 4}$	·0170	$\cdot 0048_5$	$\cdot 0121_5$	Ordinary Flint
D′ (Prism)	1·516	$63_{\cdot 7}$	·0081	·0024	·0057	Boro-Silicate Crown
E′	1·551	$53_{\cdot 0}$	·0104	$\cdot 0030_5$	$\cdot 0073_5$	Baryta Light Flint
F′	1·533	$58_{\cdot 0}$	·0092	·0027	·0065	Zinco-Silicate Crown*
G_1'	1·648	$33_{\cdot 9}$	·0191	·0054	·0137	Dense Flint
G_2'	1·516	$63_{\cdot 8}$	$\cdot 0081_5$	·0024	$\cdot 0057_5$	Boro-Silicate Crown
H_1'	1·516	$63_{\cdot 7}$	·0081	·0024	·0057	Boro-Silicate Crown
H_2'	1·648	$33_{\cdot 9}$	·0191	·0054	·0137	Dense Flint
K′	1·515	$63_{\cdot 9}$	$\cdot 0080_5$	·0024	$\cdot 0056_5$	Boro-Silicate Crown

* Baryta Light Flints are generally used for graticules, but the values found for this glass correspond more with those of a Zinco-Silicate Crown. Compare this with the values for the graticule in the periscope sight, where a Baryta Light Flint has been used.

Prism. The prism D′ in this instrument is designed to deflect the light through 90° and to reverse the field. It is shown in Fig. 7 A. The light enters at the face *a′*, is reflected internally at *b′* and then at *c′*, and passes out of the prism at the face *d′*. The path of the central ray is indicated by means of arrow-heads.

The angles between the faces are given in the following table, the results being accurate to about ± 2″ for the 90° angles and to about ± 5″ for the others.

Angle between	
a' and b'	44° 56′ 10″
b' ,, c'	74° 26′ 15″
a' ,, c'	89° 58′ 48″
c' ,, d'	67° 28′ 47″
a' ,, d'	90° 0′ 17″

Graticule. The cross-lines on the flat surface *a* of the lens F′ are similar to those described in connection with the periscopic sight. The thicknesses and separations of the different portions are given in the following table, the references being to Fig. 3 B

	cm.
x_1	·0026
x_2	·0027
x_3	·0014 broadening at centre of lens to ·0015 cm.
x_4	·0013
x_5	·0013
x_6	·0027
y_1	·0117
y_2	·0164
y_3	·0104
y_4	·0102

Angle of arrow = 60·5°.

No variation in the thickness of the lines, apart from those mentioned above, greater than ± ·0001 cm. was found.

Colour Filters. The colour filters show the same general characteristics as regards percentage transmission throughout the visible spectrum as those in the periscopic sight (see Fig. 4).

(3) VARIABLE POWER SIGHT.

The instrument is marked Carl Zeiss, Jena, 15 cm. Tbts. K.L./45 Nr. 1411 R, 5–15 × 10° – 3·3°, P.Sch. Z.C./xxxiv, 40.

(A) Mechanical Properties.

General Characteristics. A photograph of the dissected instrument is shown in Fig. 8. The mechanical details of the instrument are shown in section in Fig. 9. The main tube 1 has at one end a collar 1′, the bottom part of the rim of which is partially filed away, as shown in Fig. 9 A, which is a cross-section through XX. This has evidently something to do with the method of obtaining the correct orientation of the instrument relative to the gun mount.

Metals Employed. The sight is almost entirely constructed from steel. The graticule cell 5 and the tubes 13 and 14 are, however, made of aluminium or an aluminium alloy; the ring 2′, the excentric ring 3′ round the objective cell, the tube 24, the bush 26, and all the parts (such as 25, 29, 30 and 35) connected with the colour filter holder, except the spindle and lever, are made of brass; in the spray excluder (Fig. 9 E) the hinged lid 49 and the collar with the projection 51 are brass, the rest of the spray excluder being of steel.

Protection against Scattered Light. As in the other two instruments, the inner surfaces of such tubes or portions of tubes as would give rise to scattered light in the system (tubes 2, 4, and 8 for example) have fine screw threads cut on them so as to diminish the amount of light reflected from them. A short tube 23″ has been pressed inside the tube 23 where it joins on to the main part of the instrument. This inner tube has a rough surface, as though it had been sand blasted.

Water-tightness. In order to secure that the instrument should be quite water-tight reliance seems to have been placed chiefly on the excellent fit of the different parts. The grease employed at the joints is practically the same as that described on p. 319. The brass ring 2′ is evidently employed to prevent moisture from getting in at the screws which fix the tube 2 in its position.

Objective and Graticule Cells. Into the objective end of the tube 1 there is screwed a tube 2 which contains the objective cell 3; this cell is supplied with an excentric adjustment 3′, and the rim of the cell is bezelled over the edge of the objective to hold the lens in position. Another tube 4 is screwed into tube 2 and has at the end away from the objective the cell 5, containing the graticule lens B, screwed to it. At the edge of the graticule cell there are two slots covered by glass windows, one of which is shown at 6; the angular separation between the centres of the slots is 90°. Each of these comes opposite a slot 7 in the main tube 1. This arrangement is to allow the cross-lines on the graticule lens B to be illuminated from outside.

Variable Power Mechanism. Immediately behind the graticule lens a tube 8 is screwed into the main tube 1, and any relative movement of the two is prevented by locking screws. An angular space is left between these two tubes, into which is placed a third tube 9, free to revolve about its axis relatively to tubes 1 and 8. To facilitate such motion the rear end of the tube 9 which projects beyond the end of tube 1 is knurled, but any relative movement parallel to the telescope axis is prevented by the ring 10 which is rigidly attached to the tube 8. The cells 11 and 12 of the erecting lenses C and D are carried in holders 13 and 14 which slide in tube 8, bearing only along four strips parallel to the axis of the tube, as shown in Fig. 9 B which is a section through X′X′. These holders are prevented from rotating during translation by having guides 15 and 16 screwed to them which engage in a slot 17 cut in the tube 8 parallel to its axis. Additional guides 18 and 19 are fitted on the top of 15 and 16, and are prevented from rotating by the use of square pins and holes. The outer parts of the latter guides, shaped as circular cylinders, engage in grooves 20 and 21 milled on the inner surface of tube 9. The development of these grooves is shown in Fig. 9 C. Except at one end, where holes are drilled through to enable the guides 18 and 19 to be fixed in position, these grooves extend only half way through the material of the tube. It is now clear that, as tube 9 is revolved, the separation of the erecting lenses C and D is varied in accordance with a law determined by the shapes of grooves 20 and 21, and the power of the instrument is thereby altered. The scale of powers (from 5 to 15) is engraved on a ring 22 which is fixed to the knurled portion of the tube 9

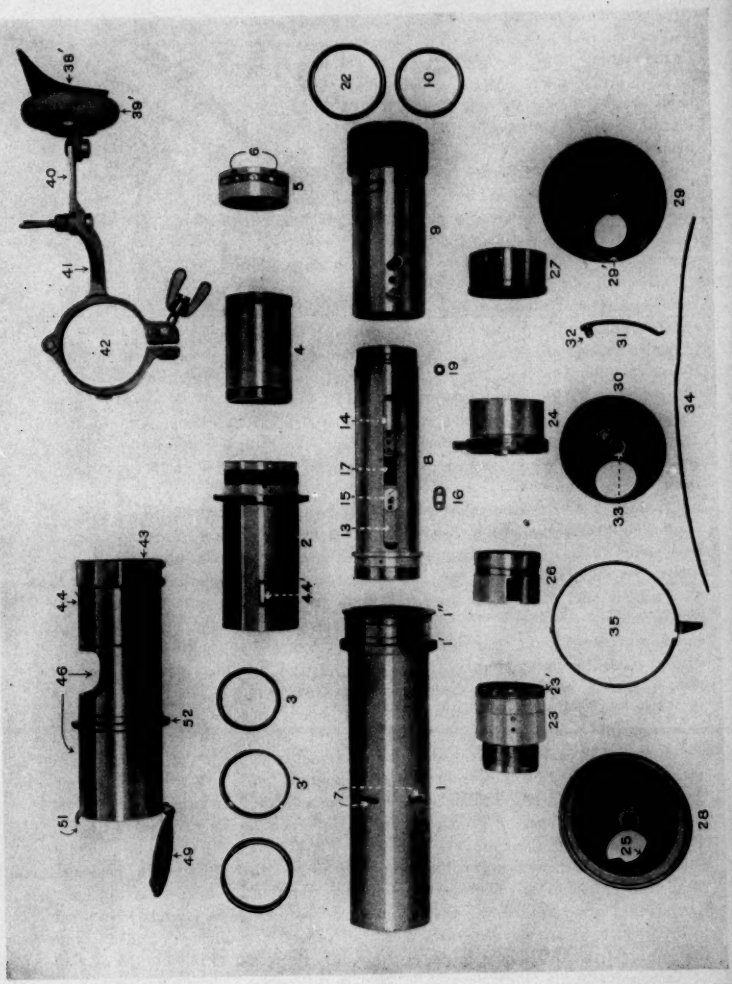


Fig. 8. Variable power sight.

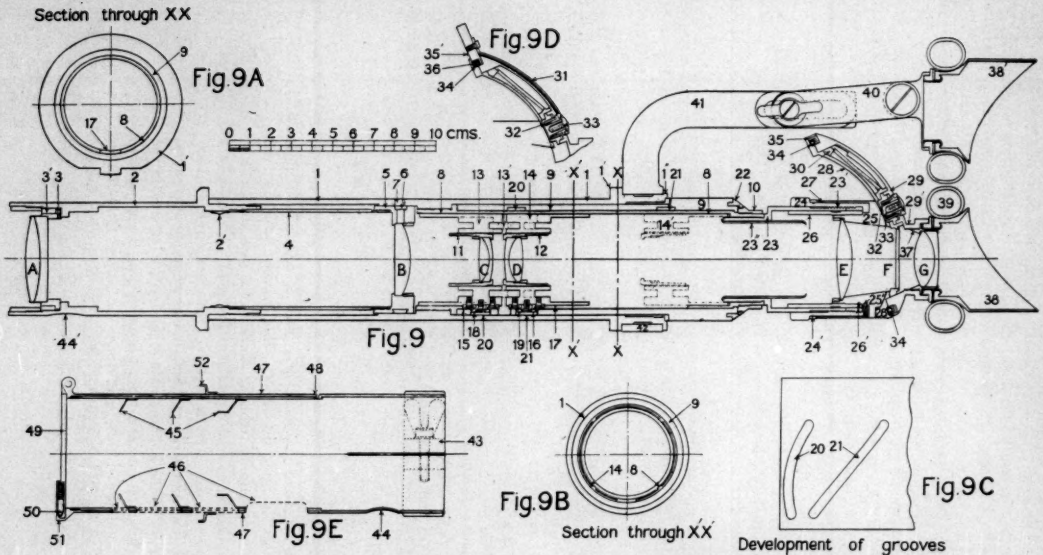


Fig. 9. Variable power sight.

by means of three locking screws bearing on a grooved portion of the ring; this arrangement allows the correct position of the scale relative to the tube 9 to be determined and fixed after the instrument has been assembled. The fixed indicator is engraved on the ring 10. The positions of the holders 13 and 14 shown in Fig. 9 correspond to the highest power (15×); the positions for the lowest (5×) are indicated by dotted lines at 13′ and 14′. (The position 13′ cannot be shown very distinctly as it lies between the positions 13 and 14.)

Eye-piece Focussing Adjustment. The tube 23, which screws into the end of the tube 8, has at the eye-piece end fourteen spiral threads 23′ cut on its outer surface. The tube 24 has corresponding spiral threads cut on its inner surface. The focussing adjustment of the eye-piece is made by rotating the tube 24 relative to the tube 23; in this way the eye-piece system as a whole is moved towards or away from the rest of the instrument. The main eye-piece tube 25 is prevented from rotating with the tube 24 by the use of a bush 26 with a longitudinal slot which works over a guide piece attached to the inner surface of 23; this bush is fixed to 25 by means of a locking screw 26′. A dioptre scale, reading from + 3 to − 4, is engraved on the tubular shell 27, and a fixed indicator mark is engraved on the eye-piece tube 25. The shell 27 is attached to the tube 24 by means of three locking screws which bear on a groove 24′ in the latter. This arrangement allows of the correct relative position of the scale and the tube 24 being obtained. A pin which passes through the tube 24 fits into a groove 25′ extending half-way round the tube 25. This pin and groove arrangement limits the rotation of the tube 24 to an angle of approximately 180°.

Colour Filter Holder. A saucer-shaped portion 28 is soldered to the tube 25. Between it and the cover 29 the colour filter holder 30 rests. The holder consists of a saucer-shaped framework with four circular holes, three of which have glass colour filters F fitted in them. The method whereby the different filters can be brought successively into the field of view is as follows. The lever 31 (see Fig. 9 D which shows a partial section almost at right angles to that shown in Fig. 9) has attached to it a spiral strip 32 which makes a friction grip round the spindle 33 of the holder. When the lever is rotated in the clockwise direction (as seen from the eye-piece), the spiral strip tightens round the spindle and drags the colour filter holder with it. A slot at the edge of the portion 28 limits the rotation to 90°. A spring catch and slot mechanism at the edge of the

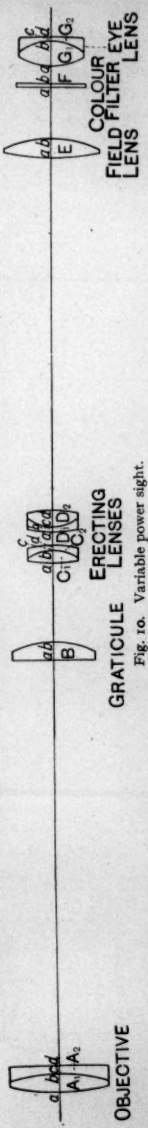


Fig. 10. Variable power sight.

holder serves to retain the holder in its new position. The lever is then brought back to its original position by the action of a coiled spiral spring 34, which during the clockwise rotation of the lever has been compressed by the ring 35, the extremity of the lever being attached by a screw to a projection 35′ of the ring. The ends of the spiral spring, which extends almost round the complete circle, press against two pins, one on the cover 29 and the other (36 in Fig. 9 D) on the ring 35. When the lever is allowed to return to its original position, the friction grip of the spiral strip 32 diminishes, so that the filter holder is not brought back with it. Thus each filter can be brought in succession into the field of view by a clockwise rotation of the lever through 90°, the lever being released after each operation.

Eye-Lens Cell. The eye-lens cell 37 is screwed into the tubular portion 29′ of the cover 29. The rim of the cell is bezelled over the edge of the eye-lens G in order to hold the lens in position.

Eye-piece Cap. A rubber eye-piece cap 38 of the asymmetrical type is provided. The cap is held in position by a hollow rubber ring 39. A similar eye-piece cap 38′ for use with the other eye is fitted on an adjustable arm 40 which can be clamped in any convenient position to a slotted arm 41 by means of a bolt and winged nut. This latter arm can be attached to the collar 1′ of the main tube 1 of the instrument by means of a hinged clamping ring 42 which is secured by a hinged bolt and winged nut. One half of the rim 1″ of the collar 1′ is of larger diameter than the other half, and this limits the rotation of the arm 41 about the axis of the telescope, as a screw projecting from the clamping ring 42 comes up against the ends of the portion of larger diameter. This arrangement is evidently to allow of the use of the auxiliary eye-piece cap with either the right or the left eye, both eye-piece caps being capable of rotation about their own axes.

Detachable Spray Excluder. This is shown in section in Fig. 9 E. It can be fitted on the tube 2 and held in position by means of a split ring clamp 43. The tongue 44 fits into the groove 44′ (Fig. 9) and thus ensures that the spray excluder takes up its correct position relative to the instrument. The diaphragms 45 and holes 46 are similar to those of the spray excluder belonging to the right angle sight. The outer tube 47 may be rotated about its axis, and a spring catch and slot arrangement 48 serves to secure it in one or other of the two positions in which the holes in the inner tube are either open or closed. The spray excluder has a hinged lid 49 with a spring catch 50 which is held by the projection 51 when the lid is closed, and by the annular collar 52 when the lid is open.

(B) Optical Properties.

A section of the optical system of the sight is shown in Fig. 10. The optical data are as follows:

Power, Definition, etc.

	Lowest power	Highest power
Effective aperture of objective	4·05 cms.	4·05 cms.
Diameter of emergent pencil	·81 cm.	·27 cm.
Magnifying power	5	15
Angular field of view	10·5°	3·5°
Fraction of field over which the definition is good and there is freedom from colour	1/3	1/3
Colour in outer parts of field	Very slight	
Focussing range	+ 2·5 to − 5 D	

Radii of Curvature, Dimensions of Lenses, etc.

All dimensions in cms.

Lens	Surface	Radius of curvature*	Axial thickness	Diameter	Approximate focal length		Separation	
A_1	*a*	+ 8·97	·771	4·2	7·9	17·5	A to B	16·8
	b	− 7·30	—	—	—		B to C†	3·3
A_2	*c*	− 7·29	·372	4·2	− 13·9		C to D†	·5
	d	− 47·7	—	—	—		D to E†	15·3
B	*a*	∞	·741	3·5	7·6		E to F	2·1
	b	− 4·07	—	—	—		F to G	·7
C_1	*a*	+ 13·95	·500	2·1	3·1	8·2	—	
	b	− 1·83	—	—	—		—	
C_2	*c*	− 1·82	·203	2·1	− 5·2		—	
	d	− 4·54	—	—	—		—	
D_1	*a*	+ 5·75	·220	2·1	− 4·1	6·1	—	
	b	+ 1·69	—	—	—		—	
D_2	*c*	+ 1·69	·673	2·1	2·5		—	
	d	− 4·65	—	—	—		—	
E	*a*	+ 10·03	·814	4·0	6·3		—	
	b	− 4·69	—	—	—		—	
F	*a*	∞	green ·14 orange ·20 neutral ·15	3·0	—		—	
	b	∞	—	—	—		—	
G_1	*a*	+ 2·64	1·046	2·7	2·3	4·8	—	
	b	− 2·06	—	—	—		—	
G_2	*c*	− 2·06	·182	2·7	− 3·9		—	
	d	− 14·54	—	—	—		—	

* Surfaces are considered positive when they are convex to the incident light (the light being supposed to enter the instrument at the objective) and negative when they are concave to the incident light.

† These values are for the case shown in Fig. 9, namely, for the power 15 and the zero position of the eye-piece focussing adjustment.

Refractive Indices and Dispersions.

Lens	n_D	ν	Medium dispersion *C—F*	Partial dispersions *C—D*	Partial dispersions *D—F*	Type of glass
A_1	1·521	63·5	·0082	·0024$_5$	·0057$_5$	Boro-Silicate Crown
A_2	1·621	36·2	·0171	·0049	·0122	Ordinary Flint
B	1·533	58·0	·0092	·0027	·0065	Zinco-Silicate Crown*
C_1	1·520	63·7	·0081$_5$	·0024	·0057$_5$	Boro-Silicate Crown
C_2	1·603	38·2	·0158	·0045	·0113	Ordinary Light Flint
D_1	1·603	38·2	·0158	·0045	·0113	,, ,,
D_2	1·520	63·1	·0082	·0024$_5$	·0057$_5$	Boro-Silicate Crown
E	1·517	65·0	·0079$_5$	·0023$_5$	·0056	,, ,,
G_1	1·540	60·0	·0090	·0027	·0063	Barium-SilicateCrown
G_2	1·618	36·0	·0169	·0048	·0121	Ordinary Flint

* Baryta Light Flints are generally used for graticules, but the values found for this glass correspond more with those of a Zinco-Silicate Crown.

Graticule. The cross-lines are engraved on the flat surface *a* of the lens B. They are similar to those described in connection with the periscopic sight. The thicknesses and separations of the different portions are given in the following table, the references being to Fig. 3 B.

	cm.		cm.
x_1	·0039	x_6	·0049
x_2	·0037	y_1	·0093
x_3	·0015	y_2	·0176
x_4	·0016	y_3	·0088
x_5	·0014	y_4	·0107

Angle of arrow = 58°.

No variation greater than ± ·0001 cm. has been found in the thickness of any of the lines.

The edge of the graticule lens B is silvered except for the two portions which come opposite the windows 6 (Fig. 9). The silver deposit is covered with a layer of black paint.

Colour Filters. The instrument is provided with three filters—green, orange and neutral. They show the same general characteristics as regards percentage transmission throughout the visible spectrum as those in the periscopic sight. (See Fig. 4.)

General Remarks. In all three sights the fit of the different parts is excellent, and the instruments exhibit first-class workmanship. Each collar or cap which screws into position is held in its position by means of locking screws. Some of these locking screws were difficult to locate, and most of the parts of the instruments were so tightly screwed into position that it was extremely difficult to unscrew them.

The edges of all the doublets were covered with a layer of black paint. The general finish of the optical parts of the instruments is somewhat inferior to that of Zeiss instruments which have been examined in our Department in the past.

In conclusion, we desire to express our indebtedness to Mr T. Smith, B.A. for his keen interest and valuable advice in connection with the examination of the instruments, Mr A. G. Williams, M.B.E. and Mr W. J. Stockwell, of the Optics Department, who carried out the tests on the power, definition, etc., Mr L. C. Cordle of the Optics Department for the photographs of the dissected instruments, and Mr W. S. Walker of the Aerodynamics Department for his painstaking and careful work on the sectional drawings.

DESCRIPTION OF GOERZ SUBMARINE PERISCOPE ADAPTED FOR HIGH-ANGLE WORK

By L. C. MARTIN, D.I.C., A.R.C.Sc., B.Sc.

Read, 12th June, 1919.

The main optical system of the periscope is of the opposed telescopes type. (Fig. 1.) The main interest centres in the part which comprises the "eye-piece" of the topmost telescope. A diagram is given of the optical system employed. (Fig. 2.)

A is a silvered right-angle prism with an aperture of $3{\cdot}5 \times 3$ cms. It rotates about an axis in the centre of its hypothenuse in order to command various angles of view. The lenses B and E are withdrawn when the higher magnification is desired. When these lenses are not in action, the light passes from A through a small prism C (angle 10°) and suffers two internal reflections in the larger prism shown in the diagram, which has base angles of 50° and 110°. The side of the prism remote from the lettering in the diagram is silvered. It will be seen that the small prism is introduced for the sake of achromatism. It is of the same glass as the main prism. The lens D now forms an image of the external field in the plane of the field lens G on which a graticule is engraved.

When it is desired to use the lower magnification system the lenses B and E are brought into position. B is mounted in a rotating frame, the mechanism being such that a single lever at the base of the instrument brings both these lenses into action simultaneously. B is a negative lens with a power of approximately $-38\,D$, E is a non-cemented doublet which forms an achromatic combination. The effect of the two lenses B and E is evidently that of a reversed Galilean telescope which of course reduces the size of the image formed in the graticule. F is a plate of glass with plane surfaces for the purpose apparently of keeping the surface of the field lens free from dust, as the space below the plate is a closed tube. Surrounding the rim of the field lens, which is polished, is a ring of radium paint which serves at night for the purpose of illuminating the lines and scale of the graticule. These lines are curved sufficiently to compensate for the distortion effects of the system. Several points are of interest in connection with the design of the main system. The tube is lined internally with aluminium pressed up into rings for the purpose of obviating reflection from the walls of the tube. A flat brass tube passes from the base of the instrument to the top for the purpose of changing the air in the interior, which is accomplished by a pump attached at the lower end. The motions of the top prism and the two lenses B and E are controlled by means of flexible steel "Bowden wire" running upwards from the control handles at the base.

K and L are both triple cemented lenses with the usual silvered right-angled prism between them.

The two powers available are 1·5 and 6.

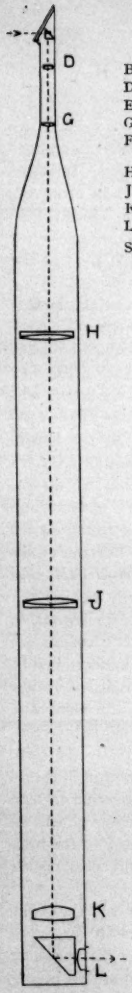


Fig. 1.

Lens	Diameter	Approximate power in dioptres
B	·9 cm.	− 38
D	2·4	+ 5
E	2·4	+ 13
Glass plate	2·8	0
Field-lens and Graticule *G*	4·25	+ 4
H	10·8	+ 0·4
J	10·8	+ 0·4
K	10·2	+ 4
L	3·5	+ 10

Separation of H and J = 220 cms. approximately.
Figures diagrammatic.

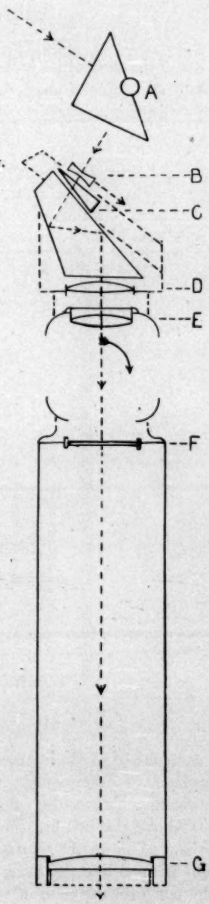


Fig. 2.

THE BAKER AIR SEXTANT

By Instructor-Commander T. Y. BAKER, R.N., B.A.

Read, 12th June, 1919.

One of the difficulties in using an ordinary sextant in aircraft lies in the uncertainty as to the depression of the visible horizon below the true horizontal. In order to avoid this uncertain correction to the altitude of the heavenly body observed, the present sextant has been designed to utilise the part of the horizon directly below the sun and star, and also that part in the opposite azimuth.

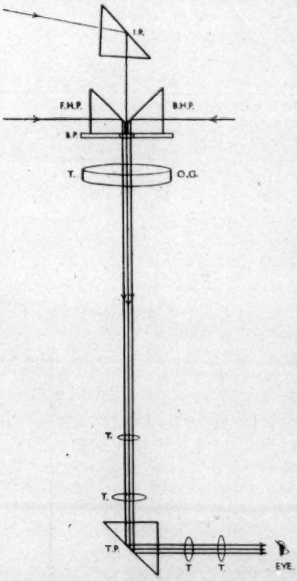


Fig. 1.

The general optical design of the instrument is shown in Fig. 1. A telescope *TTT* has the main part of its axis vertical and has a right-angled bend produced by a prism *TP*. The *OG* of the telescope is at the upper end of the system and the four lenses of the eye-piece are arranged as shown in the figure. The eye looks into the eye-piece of the telescope in a horizontal direction as shown. Above the *OG* is a plate, *BP*, upon which are mounted two prisms whose functions are to collect light from the front horizon under the sun by the front horizon prism *FHP*, and from the back horizon (directly behind the observer) by the back horizon prism *BHP*. The reflecting faces of these two prisms are at right angles to one another and as a result, the field of view (Fig. 2) consists of a view of the front horizon which is the right way up and of the back horizon which is inverted.

If it is assumed, as is normally the case, that the dip is of the same amount all round the horizon, then the true horizontal as seen by the observer through the telescope will be just as far from the image of the front horizon as it is from the image of the back horizon, in other words, the true horizon is half-way between the two visible horizons whatever the value of the dip may be.

Above the two horizon prisms *FHP* and *BHP*, is a third prism *IP*, the index prism. This prism rotates round an axis perpendicular to the plane of the paper and is used like the index mirror of an ordinary sextant, to reflect the image of the sun into the field of view. Light from the sun, after reflection at this prism,

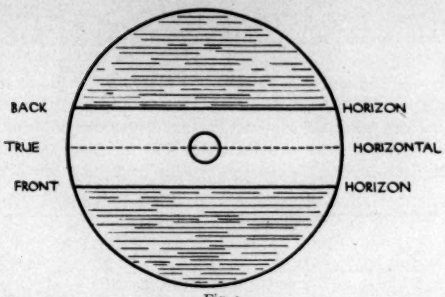


Fig. 2.

passes into the telescope system through a small circular hole drilled centrally through the two horizon prisms. By this index prism the image of the sun is brought down to bisect the space between the two visible horizons, thus dispensing with all corrections for the dip of the horizon and the semi-diameter of the sun.

A general view of the instrument is shown in Fig. 3. The upper end of the body of the casting is carried upwards in a portion which forms a bracket to contain the journal in which a circular plate about two inches in diameter can be rotated. On the inner side of this plate and above the two horizon prisms the index prism, *IP*, is fixed, the rotation being actuated by a worm and worm-wheel. The spindle of the worm (*WS*) has a divided head, *DH*, at the top and a knurled head, *KH*, at the bottom for moving it. The worm-wheel has 72 teeth to the complete circle, so that, as the scale of angles in a sextant is half the ordinary scale, each tooth is equivalent to 10° of measured altitude. The worm-wheel is enclosed in a case, *WWC*, in which a small portion has been cut away in order that the angle of the nearest ten degrees may be read. For this purpose, each ten degrees mark is marked on the worm-wheel. Intermediate degrees and minutes are read on the divided head *DH* of the worm spindle, *WS*, against a pointer, *WSP*, fixed to the

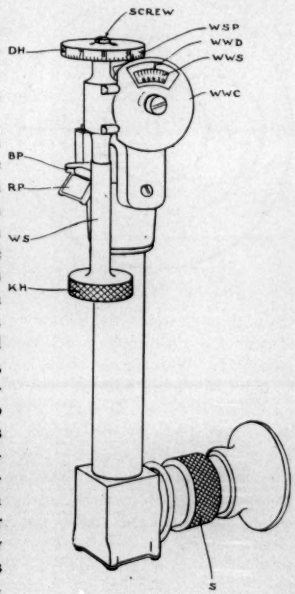


Fig. 3.

casing. The division of the divided head is into 60 parts, so that the smallest division represents 10 minutes. As this division is about 1/10 inch, it is possible to read the sextant to 2 or 3 minutes.

When observing the sun, it is necessary to use a dark shade to cut down the sun's light.

A small refracting prism *RP* is placed for use, if necessary, in front of the front horizon prism. Its function is to deflect light from the horizon sideways and is to be used when the part of the horizon directly under the sun is obscured by a strut of the machine or some other obstruction. This prism can be reversed for displacing the light in the opposite way.

There is a certain difficulty when first using the instrument in seeing both horizons and the sun at the same time. This is due to the fact that the telescope has been made of low power (about 3 diameters) in order to allow of its having a wide field. The exit pupil is of the shape shown in Fig. 4, consisting of a central

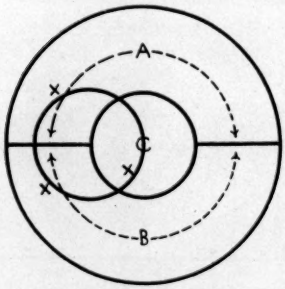


Fig. 4.

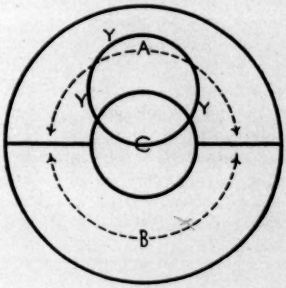


Fig. 5.

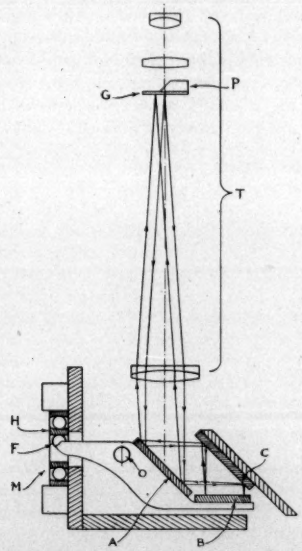
part *C* through which the light from the sun emerges and an upper and a lower segment *A* and *B* through which light comes from the front and the back horizons respectively. When in use, the exit pupil of the instrument comes at the plane of the pupil of the eye and the three parts of the field will only be equally bright and visible if the actual pupil of the eye covers equal areas of *A*, *B*, *C*, such as the position shown by the circle *XXX*. If the eye be held so that its pupil falls in a position *YYY*, shown in Fig. 5, the back horizon will have disappeared as no light from it (area *B*) passes into the eye. With the flexibility of the rubber eye-cap it is possible to move the eye about, so as to make the three parts of the field equally bright and visible, but proficiency in this respect can only come by practice.

AN INSTRUMENT FOR TESTING THE ACCURACY OF BALL BEARINGS

By Instructor-Commander T. Y. BAKER, R.N., B.A.

Read, 12th June, 1919.

This instrument is designed for testing the accuracy of the ball bearings used at the Admiralty Compass Department. These bearings support the axle of the main gyro-wheel which weighs 50 lbs. and runs at a speed of 8,600 r.p.m. It is essential that the circular hole of the moving part of the bearing should be concentric with the ball race, otherwise the gyro-wheel will not be running true, and a maximum eccentricity of 1/10,000th of an inch is all that can be permitted.



The principle of the instrument is best shown by a sketch. *M* is a ball bearing clamped into position by means of a spring arm which keeps the outer rim fixed, leaving the inner rim free to be turned by hand. *F* is a feeler arm which presses up against the top side of the inner rim. This arm is pivoted at *O*, the distance *FO* being approximately one inch. The other part of the arm holds two mirrors

A and *B*, *A* being inclined at 45° approximately, and *B* being approximately horizontal. *C* is another mirror fixed to the instrument approximately parallel to the mirror *A*. *T* is an auto-collimating telescope. Light enters the instrument by means of the prism *P*, is reflected down the barrel of the telescope, passing out of the *OG* as a parallel beam. It is reflected again at *A* and *C* on to the mirror *B* from which it retraces its own path, entering the eye at the top of the telescope. A scale is fixed in the focal plane of the telescope and an image of this scale is produced in the same plane by the light which has undergone three reflections at the mirrors on the moving arm and two reflections at the fixed mirror.

An eccentricity of 1/10,000th inch in the bearing makes the feeler move through a distance of 1/5000th inch. The arm has therefore a total angular movement of about 40″. It is easily seen that this angular movement of the arm has the effect of displacing the reflecting beam through an angle of 4 minutes, an angle which when multiplied by 6, the magnifying power of the telescope, makes the displacement of the reflected scale subtend 24 minutes at the eye, an amount which is easily visible.

If a higher magnification had been desired it could have been achieved by producing further reflections on the moving part, the general law being that the angular displacement of the reflected beam is $2n\alpha$ where α is the angular movement of the moving arm and n is the number of times that light is reflected in mirrors attached to that arm.

ABSTRACT

"A Study on the Performance of Night-Glasses." By L. C. MARTIN, D.I.C., A.R.C.Sc., B.Sc., Department of Scientific and Industrial Research, Advisory Council; *Bulletin*, No. 3.

The paper commences with a discussion of the results of various experimenters on the relation between the minimum brightness perceptible by the eye and the angular area of the stimulus source. An absence of satisfactory agreement makes further work necessary.

If without a telescope the threshold brightness for an object subtending an angle a be T, then $T \propto a^n$ (say). When using a telescope giving magnification M, the threshold T will vary as M^{2-n} for a constant object, *if the exit pupil is smaller than the pupil of the eye*. Advantage in seeing can always be obtained (special particular cases excepted) if the exit pupil remains larger than the pupil of the eye by increasing the magnification. The first experimental work described correlates the results of naked eye and telescope acuity experiments in faint light, and good agreement is found between observed and calculated values. Experimental methods and precautions are described in detail.

Further experiments are concerned with the determination of the index n. This is found to have a steady value of about 2 to 2·6 in various cases while a varies between 10 to 60 minutes approximately. The variation of n occurs between different types and relative brightnesses of object and background. At about 60 minutes and over the value of the constant appears to change to 1.

Applying these results to the consideration of the threshold of vision when using telescopes, the following deductions are made:

(1) Advantage will be secured in all cases where magnification can be increased without diminishing the brightness of the image.

(2) Advantage after this point will still generally be secured for objects subtending angles between 1 and 60 minutes in the field of view of the instrument, but when the latter condition is reached the performance will fall off.

(3) The apparent field of view should be made as large as possible.

(4) Every care should be taken to screen the eyes from all light brighter than that in the field of view.

Practical experiments in the field and elsewhere confirmed these conclusions except that when in some cases the object sought fills too large a proportion of the field of view increased magnification is not desirable even though the light is not cut down.

The following conclusions were reached:

(1) Considerations limiting the useful increase of magnification for day use with hand binoculars are even more important for night work. For hand use alone a magnification of 7 is a little high.

(2) Where some definite small object is to be observed and where a stand for the instrument is to be employed (in flag signalling, etc.) magnification may be usefully taken higher, according to the amount of light available.

(3) Binocular instruments are very desirable for comfort.

(4) A large apparent field of view confers an immense advantage in "confidence" and ease of observation.

(5) Since for hand use low magnifications are employed the exit-pupil should be 7 or 8 mm.

(6) The magnification that can be used with advantage varies greatly with the amount of light available. When the night is very dark, only comparatively large objects are generally perceptible and the use of glasses in this case is of little value, especially if the objects viewed subtend too large an angle in the field of view. Smaller objects may, however, be seen against the sky, and a larger magnification is then useful. For general purposes the power should not be too high, probably 5 or 6 would be as useful as any for a hand instrument.

(7) Diffuse light in the images arising from "ghosts" and filmed surfaces is an enormous drawback, especially when working at dusk with a sky much brighter than the objects viewed. Certain instruments appear very liable to this effect and tests have been made on this point*.

The paper concludes by giving suitable data for a stand telescope to work under given conditions. For general use an instrument having an 80 mm. O.G. and 3 powers ($\times$ 10, $\times$ 20, and $\times$ 30) is recommended.

L. C. M.

* *The Optician*, August 2nd, 1918.